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December, 1982

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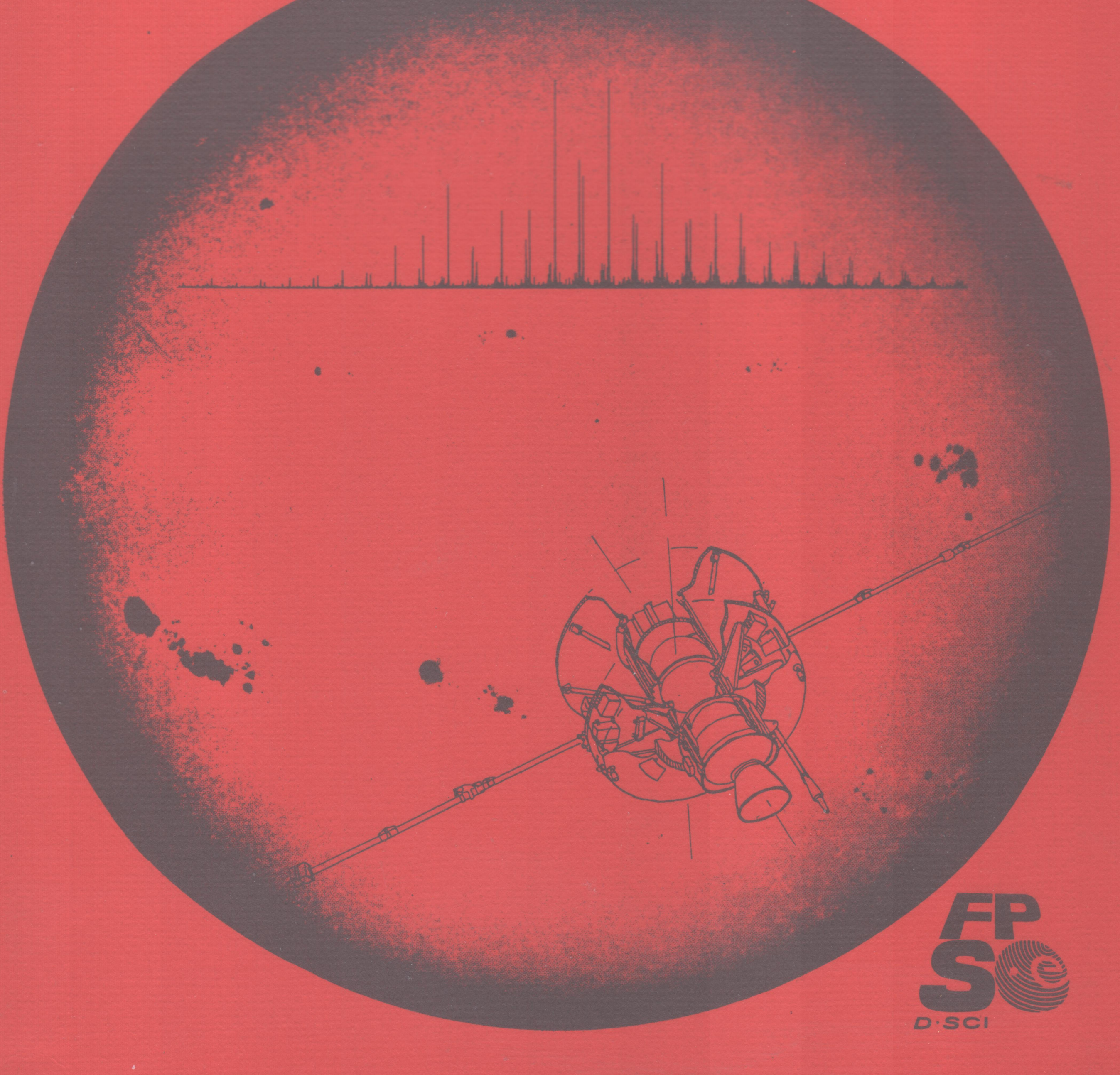
Disco

RESULT OF THE PHASE A STUDY



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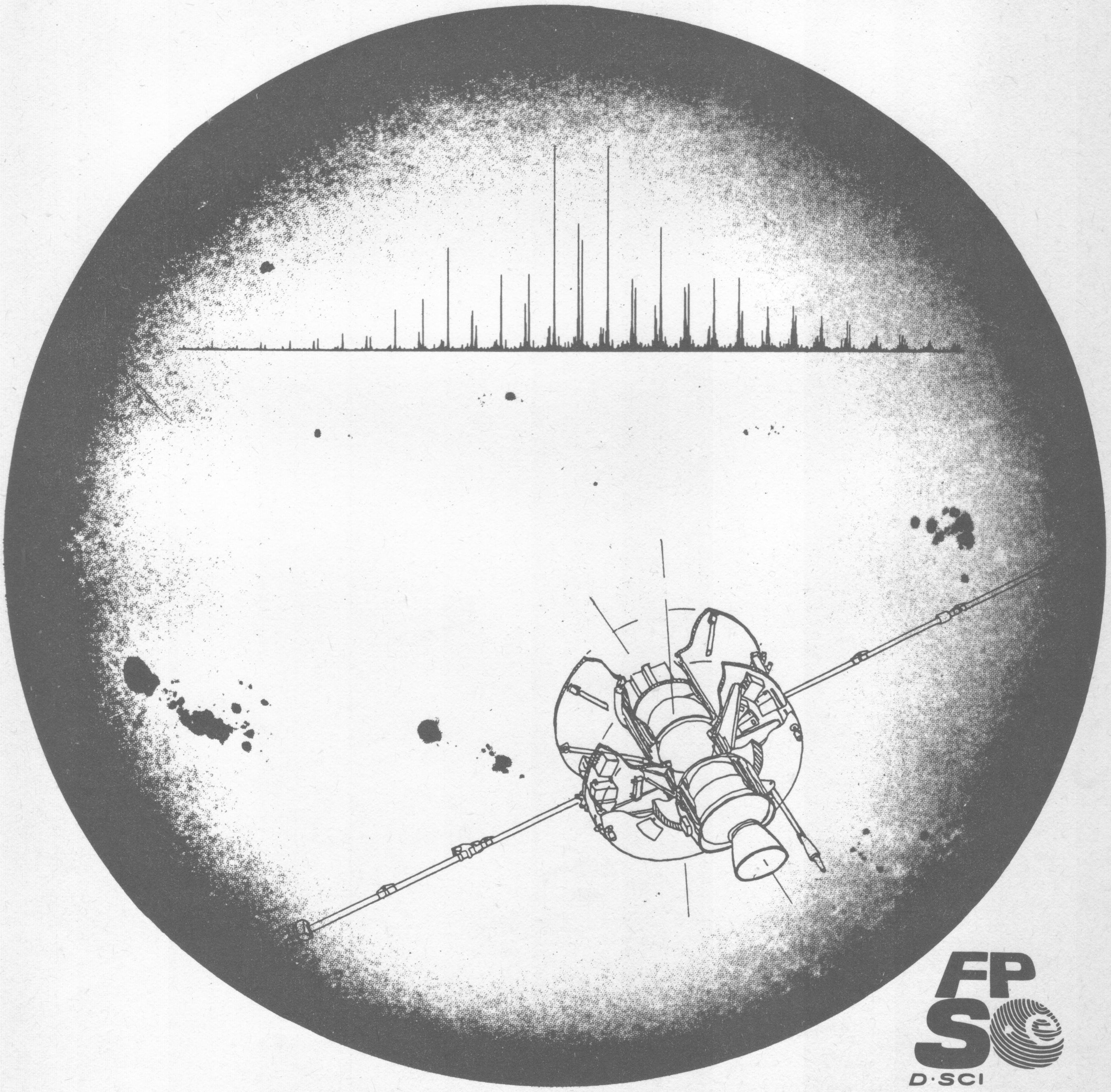

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Foreword

DISCO (Dual Spectral Irradiance and Solar Constant Orbiter) was proposed by R.M. Bonnet, D. Crommelynck, V.P. Delaboudinière, and G. Thuillier in response to the call for Mission Proposals issued by ESA in July 1980. A first assessment was made and the results published in report SCI(81)3 of May 1981. After reviewing the results the Space Science Advisory Committee recommended that the science payload be expanded to include baseline in-ecliptic measurements in support of ISPM, in addition to the solar seismology and solar irradiance measurements. The reassessment was duly carried out and reported in SCI(81)6.

This led to the decision by the SPC (Science Programme Committee) to proceed with a phase A study for DISCO. The industrial part of the study was carried out between April and November 1982 by British Aerospace (BAe), Bristol.

The study was supported by a Science Working Team (SWT) and the present document summarises the results of the scientific and technical phase A study activities. The scientific part of this document was prepared by the SWT working in close cooperation with the Study Scientist from Space Science Department, ESTEC. The technical part was prepared by the Future Projects Study Office, ESTEC with the support of specialists from the Directorate of Operations and the Technical Directorate.

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DISCO

(A Solar-Seismology and Heliospheric-Structure Observatory)

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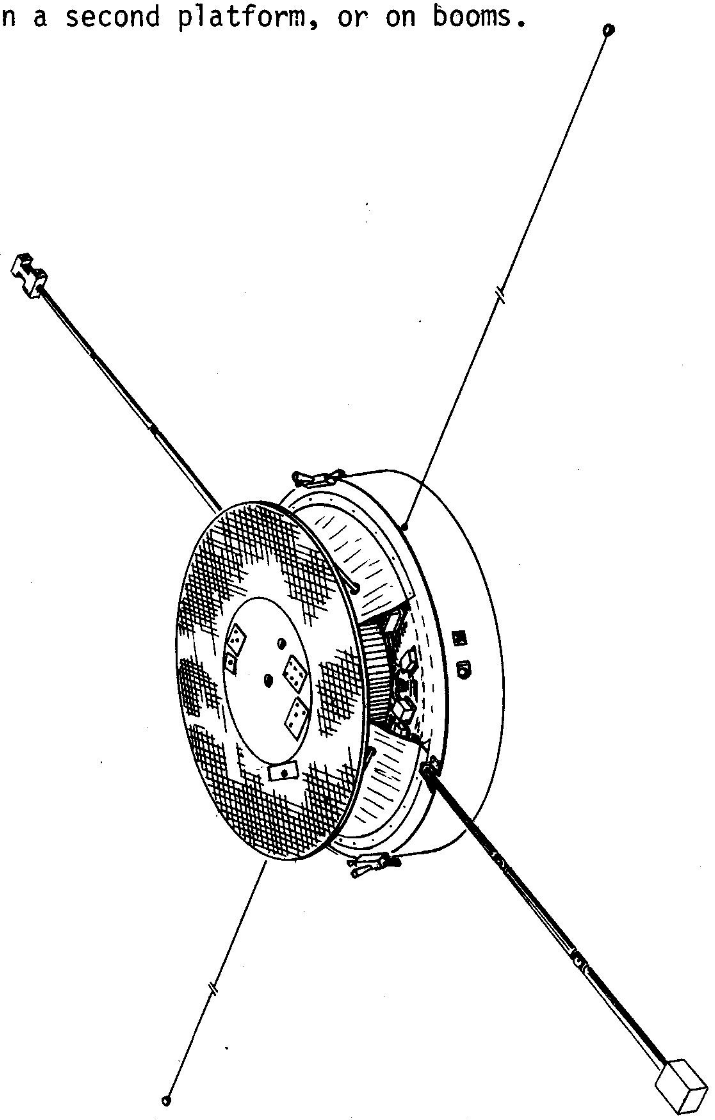
EXECUTIVE SUMMARY

DISCO will, for the first time, perform spaceborne solar seismology. Simultaneous observations will be made of the oscillations of the solar global velocity and luminosity. This will supply data which allows the internal structure of the Sun to be probed with previously unavailable accuracy and sensitivity. Space observations are free from atmospheric perturbations, eliminate the effect of the Earth's rotation and offer a long, uninterrupted series of observations. DISCO will obtain continuous high precision measurements of the solar irradiance, and its variability, providing essential information for the understanding of the dynamics of the convection zone of the Sun. DISCO will also increase our understanding of heliospheric processes by coordinated study of optical observations on the Sun and of fields and particles measurements at 1 AU. DISCO will be a very important complement to the International Solar Polar Mission (ISPM) providing measurements in the ecliptic plane simultaneously with the high latitude passes of ISPM, and thus exploiting this unique opportunity to gain a truly 3-dimensional view of the heliosphere.

DISCO is planned to be launched in 1988, and will take between 90 and 150 days to reach its final orbit around the L_1 Sun-Earth Lagrangian point. It will be a simple spinner, with a spin rate of 5 rpm, and the spin axis pointing towards the Sun. The Sun pointing experiments are accommodated on a special platform for fine alignment and the remaining experiments are mounted on a second platform, or on booms.



DISCO was originally proposed as a mission to study the structure of the Sun by means of global oscillations in visible light, and measurements of the total and spectral irradiance in selected bands, together with a far-UV spectrometer to study coronal holes. Simultaneously, and as a consequence of the successive launch postponement of ISPM, the heliosphere commmunity became aware of the fact that, although the solar wind in the ecliptic plane has been almost continuously monitored for the past fifteen years, a real danger exists that such essential measurements cease before or at the time of the ISPM. This concern was expressed in resolutions unanimously adopted by the ISPM Science Working Team in October 1980 and February 1982.

Following the presentation of the first DISCO assessment study, the Space Science Advisory Committee (SSAC) recommended, in June 1981, a re-assessment of the DISCO mission addressing the following scientific topics, in order of priority: 1) solar seismology, 2) baseline in-ecliptic measurements in support of the ISPM mission, and 3) measurements of the solar irradiance. The SSAC also insisted that the cost of the revised DISCO mission must not exceed that of the original proposal. A revised model payload was established to be, as far as possible, consistent with these objectives. The re-assessment study was presented to the Solar System and Astronomy Working Groups in November 1981. Subsequently, the mission was selected by the SPC for a Phase-A study.

The model payload was defined at the start of the re-assessment study, in July 1981, before the cancellation of the US ISPM spacecraft. No subsequent changes in the payload were made, both for practical (schedule) reasons and because the study payload contains experiments which supply the technical mission drivers, such as orbit and orientation stability in the presence of booms, cleanliness, EMC. The only exception was the addition of a solar X-ray/cosmic γ-ray burst experiment at the start of the Phase-A study, to replace the instrument on the US ISPM spacecraft.

To assess the scientific potential of a mission like DISCO, a two-day symposium entitled "The Global Sun and the Heliosphere as seen from the Lagrangian Point L_1" was organised at Utrecht in June 1982. At this meeting new results were presented and new ideas were suggested, demonstrating that the European scientific community is playing a major role in global solar physics as well as in heliospheric science. Another success of the meeting was the proof of both the impressive European potential for supplying instruments for a mission of the type proposed here, and of the suitability of the L_1 Lagrangian point for studies of both the global Sun and the heliosphere.

The phase-A scientific study has benefited from the scientific inputs of that meeting as well as from new, and sometimes rapid, developments in the DISCO scientific fields. So the reader of the present documents should not be surprised to find in it scientific objectives that look more ambitious and far reaching than in the re-assessment study document. A section on additional scientific objectives has also been included which illustrates how rich the scientific return of DISCO can be, both for solar system investigations and astrophysics.

1. SCIENCE OBJECTIVES

1.1 INTRODUCTION

The investigation of the solar interior is a new and significant area of research in astrophysics. The knowledge of physical conditions in the solar interior is of fundamental importance to theories of stellar evolution. Solar seismology has proved to be a valuable diagnostic tool for probing the internal structure of the Sun. Indeed, continuous observations of global solar oscillations offer, for the first time, the possibility of exploring the fundamental parameters of the whole solar interior.

Ground-based observations have already yielded many important results concerning the strongest oscillatory modes. In particular, observations have been made from the South Pole for more than five consecutive days, and more recently, a set of twin stations was able to provide 88 days of continuous observations of global oscillations. However, measurements of global oscillations from the ground have a number of limitations which are discussed in detail in Section 1.2.

Observations from space have already greatly improved our understanding of the physics of the Sun. This is as true of more traditional fields of solar studies as of those new disciplines which completely rely on the elimination of the Earth's atmosphere and other limiting aspects of the terrestrial environment. In particular, despite accurate radiometers operating continuously from the Earth for several decades, it is only when such instruments were operated in space that the solar constant and its variations could be monitored with dramatically increased precision, and total luminosity oscillations observed. Similarly, further progress in most areas of solar physics is expected to come from specific space missions.

The prime objective of DISCO is to perform, for the first time, space-based solar seismology, observing at the same time fluctuations in both the global velocity field and solar luminosity. Observations from a space platform are unambiguous: not only are they free from atmospheric perturbations but they also eliminate the effect of the Earth's rotation, assuming the correct choice for the orbit. They also offer the possibility of long, uninterrupted series of observations, comparable or longer than the expected coherence time of the oscillatory modes themselves.

The halo orbit chosen for DISCO around the Lagrangian point L_1 located between the Sun and the Earth provides extremely good observing conditions for the detection of global velocity fluctuations with high accuracy and sensitivity.

DISCO also offers the possibility to increase significantly our understanding of heliospheric processes. It is intended as a very important complementary mission to ISPM, by providing the necessary measurements in the ecliptic plane simultaneously with the high solar latitude passes of ISPM. Such reference measurements are indeed essential in order fully to exploit the opportunity offered by ISPM to gain a truly three-dimensional view of the heliosphere. On the other hand, its orbit and its Sun-pointing attitude are highly suitable to observe the solar wind with a time resolution never before attained.

The provision within the DISCO payload of instruments to image the corona will contribute to a better understanding of coronal structures, and will also provide information to link processes occurring on the sun to heliospheric phenomena observed in situ on both DISCO and ISPM. These objectives are described in more detail in Section 1.3.

In the course of a two day Colloquium "The Global Sun and the Heliosphere as seen from the Lagrangian point L_1" held in Utrecht in June 1982, the various scientific objectives of DISCO received a positive appraisal from a broadly based scientific community. The colloquium demonstrated that many European groups see DISCO as an ideal platform for instruments they have already developed or are currently developing for solar or heliospheric studies falling within the objectives as described in this report. Furthermore, a number of other objectives were also mentioned, ranging from the detection of comets to the study of interstellar matter in the solar system, the identification of cosmic gamma ray bursts and even stellar seismology, as summarised in Section 1.4.

The planned lifetime of 2 years for DISCO is sufficient both to allow the faintest solar oscillatory modes to be detected and to perform in-ecliptic reference measurements in support of ISPM, assuming that DISCO is flown during the high latitude phase of ISPM.

In order to define the DISCO spacecraft itself, a model (or study) payload was identified. This is by no means a unique complement of instruments. The final payload will be defined after the usual competitive selection process in conformity with standard procedures within ESA.

DISCO will undoubtedly be a significant space mission for the study of the Sun and the heliosphere. It will give the opportunity to European scientists who have so successfully pioneered the field of solar seismology to remain at the forefront of this new reasearch field. Having so thoroughly expressed their willingness to bring the International Solar Polar Mission to fruition, European scientists will also be able to take advantage of DISCO to gain a unique insight into the three-dimensional nature of the heliosphere.

1.2 THE GLOBAL SUN - DIAGNOSTICS OF THE SUN'S INTERIOR

One of the most importance advances in recent years in astrophysics is that,for the first time,we have the capability of diagnosing the interior of the Sun.

Helioseismology is still in its infancy but already very accurate determinations of global phenomena and properties of the Sun have proven their enormous diagnostic potential for the inner solar layers. The flux of neutrinos, for example, puts severe constraints on the composition and temperature of the nuclear reactive core. The oscillatory modes of the solar resonator which have the longest wave-lengths (or the lowest degrees in terms of spherical harmonics) sound very deep layers and are sensitive to the physical conditions of the very core. Rapid rotation of the inner layers already shows up in the rotational splitting of some of the observed modes. One characteristic of global solar observations is the possibility to achieve high absolute accuracies. For example, the actual period of the 160 min oscillation (160.01 min) is the most precisely known of all of the solar parameters.

The use of space techniques, will not only result in observations that are impossible from the ground, and will greatly enhance the precision, but in addition it will provide long continuous coverage. These observations will contain the temporal variation of these global properties and of their respective phases, which will lead to a refined understanding of the structure and dynamics of the solar interior.

Europe must continue to play its role in this growing field of interest. Not only does the expertise exist in the area of accurate radiometry and photometry, but the development of high resolution spectroscopy techniques clearly illustrates the fact that European scientists today do possess the tools necessary to properly explore this new and exciting field of research.

The main areas in which DISCO will provide a dramatic advance for the diagnostics of the solar interior are:

- The velocity oscillations will be recorded free from terrestrial effects, with an accuracy of 1 mm s^{-1}, and with greatly improved resolution.

- The luminosity oscillations, which can only be recorded from space, will provide a new tool for the interior diagnostics, in particular when carried out in coordination with the velocity measurements.

- The convection zone, solar dynamo and cycle mechanisms are probed by measurements of luminosity and perhaps by magnetic-field fluctuations on all time scales.

Measurements of the variations in the solar shape (oblateness) are also relevant to the diagnostics of the solar interior, but are not included in the present proposal, since they would require a very accurate and sophisticated 3-axis pointing platform, and since more progress is anticipated from ground-based observatories.

The following subsections will treat the above objectives in greater detail.

1.2.1 Helioseismology - Solar Oscillations

State of the art

In recent years a wealth of new information has become available from observations of dynamical oscillations of the Sun. Provided the modes of oscillation can be identified, their frequencies can be used to diagnose certain aspects of the Sun's structure in much the same way as terrestrial seismic waves have been used to probe the interior of the Earth. Both theory and observation have advanced rapidly, and already we are beginning to constrain the solar models more severely than had previously been possible. Like in the Earth, the amplitudes of the oscillations are so low that linear theory can be used to determine the frequencies.

The principal modes of oscillation can be classified according to their physics and according to their geometry. As pointed out by Cowling (1941), there are p-modes whose principal restoring force is provided by pressure, and g-modes whose principal restoring force is buoyancy. The frequencies of p-modes are determined mainly by sound speed whereas the g-modes frequencies are governed by the (potential) density gradient in the stably stratified radiative interior. In addition, there are the surface gravity waves (Cowling's f-modes).

Since, to a first approximation, the Sun is spherically symmetrical, the solutions for the normal modes are separable in time, radius and angular coordinates. The angular structure of each mode is a spherical harmonic of degree l and tesseral order m and the eigen functions in radius constitute a discrete sequence and can be labelled with an integer n, which is called the order of the mode. The degree l determines an effective horizontal wave number k. The eigen frequencies ω depend on n and l, but the spherically symmetrical modes are degenerate in m. In reality, the Coriolis forces arising from the slow rotation split the degeneracy in m.

The observations fall into two groups: those that detect modes with high l, and those which measure modes with low l. P-modes of high degree have been measured with precision by Deubner (1975), and, more recently, by Harvey.

The observations have determined the relation between k and ω for low order modes ($n < 10$). These modes penetrate only a few percent of the solar radius beneath the photosphere, and, therefore give us no direct information about the deep interior. Nevertheless, the information they provide has enabled us to eliminate standard solar models with low helium abundance. It should be pointed out, however, that this result depends on untested assumptions of the standard theory and must, therefore, be treated with caution.

Global velocity oscillations - 5 minutes range

Although it was discovered by Deubner (1975) that the solar oscillations had a modal structure as revealed in the k-ω diagram, it was not expected that these oscillations would show up in observations of the global Sun. In fact whole disc light integration has made possible the observation of low degree modes. First the Birmingham group made

Importance of space observations

Alcaline resonance cells provide a proven and simple technique of measuring global surface velocity oscillations. As the spectrum of the solar oscillations is the Fourier transform of the time velocity fluctuations, it is obvious that the highest accuracy is obtained with the longest observing time. To date, with nearly 3 months of continuous observations, the coherence time of any solar mode has not been reached. It is highly desirable that perfectly continuous measurements are obtained: together with a sharpening of the line profiles, a better determination of their frequencies and of their minute separations due to rotational splitting will vastly improve the layer by layer modelling of the Sun. Unfortunately the velocity signal is transposed by the Earth's rotation, and possibly by atmospheric fluctuations. The Earth's rotation superimposes a large velocity signal with a 24 hour period which cannot be completely eliminated due to the non-linear response of the instrument. For long period modes it may cast some doubts on the solar origin of peaks in the velocity spectrum; these doubts are dramatically enhanced when dealing with frequencies close to daily harmonics as is the case of the 160.01 min oscillation.

The effect of atmospheric fluctuations is very difficult to assess: in the actual spectra, obviously a "noise" level is recorded and is measurable. The instrumental noise (photon noise, pointing accuracies) is below that level. This noise can be either of solar origin (random fluctuations, as well as clustering of modes) or of atmospheric origin. The statistical distribution of this noise is compatible with any of these possibilities - going into space will clarify this issue, but the main improvements that one expects will come from the elimination of all the 24 hour modulation effects and from the guaranteed continuous coverage.

Space observations would allow us to obtain the spectrum of solar velocity oscillations free from terrestrial effects and without gaps in the data, thereby taking us into so far almost unexplored territory of the frequency domain, which should prove of particular importance in diagnosing the solar interior, since the lower frequencies are more dependent on the conditions in the solar core.

Rotational splitting

In principle, rotational splitting of the non-axisymmetrical modes can provide us with information about the internal rotation of the Sun. The splitting of each set of degenerate modes provides a different integral of the angular velocity of the Sun. Thus, with many modes one can perform an inversion to estimate the angular momentum distribution within the solar interior. Of course, among other things, the oblateness of the gravitational equipotentials can be inferred from the results.

Recently, new data from 88 contiguous days of ground-based observations have yielded the first indications of rotational splitting of the low order $l = 1$ and $l = 2$ p modes (Claverie et al., 1981). Although no theoretical model has as yet been able to give a consistent explanation of the observational results (Isaak, 1982; Gough, 1982b) information is now becoming available on the internal structure of the Sun, e.g. solar core rotation. Further evidence of rotational splitting has also been reported from solar diameter measurements.

These exciting new results illustrate the need for obtaining long contiguous data strings with the consequent increase in frequency resolution.

The question of the solar core rotation has been somewhat indirectly addressed in the past through the determination of the quadrupolar moment J_2, since an accurate determination of this quantity has far reaching consequences on general relativity. Solar probes, as studied by ESA and NASA in the past, would supply only one integral measure of the internal rotation of the Sun, and that with limited accuracy. If no g-mode were excited, the Solar Probe would give an evaluation of the integral measure of this rotation through J_2, which is the actual parameter needed in studies of Mercury's perihelion advances. But, if the 160 min oscillation is a low degree g-mode, and if other, yet undetected modes are excited, the situation is changed: the perturbation in the gravitational potential they produce would be a substantial fraction of the static rotationally induced oblateness if the Sun were rotating approximately uniformly. Since such a probe would spend only a few oscillation periods close to the Sun, it would be impossible to disentangle the oscillatory component of the gravitational field using a measurement of the orbit alone. In that more probable situation, helioseismology analysis will be the only way through which we shall obtain, albeit indirectly, valuable information on J_2.

Future development of oscillation spectroscopy

As is clear from the above discussion, ground-based observations have been providing us up to now with a set of frequencies - or, to use the spectroscopist's language, a line spectrum.

Lengthening the observing time has the same effect as improving simultaneously the resolving power and the efficiency of a spectrograph: the resolving power in frequency being proportional to the observing time, the noise amplitude being inversely proportional to its square root.

In analogy with the history of atomic spectroscopy, we expect a second phase in the development of oscillation spectroscopy on the Sun, involving the following areas:

- determination of accurate line shapes,
- determination of lifetimes of various oscillatory states,
- exploration of excitation and decay mechanisms,
- investigation of line broadenings and shifts,
- relative line strengths,
- determination of the continuous spectrum and its origin.

To clarify a few items in this list, we shall consider the information contained in weak lines and line shapes.

Time scales of days to weeks. The first clear evidence of solar irradiance changes was from the SMM spacecraft, launched in early 1980, near the peak of the solar activity cycle (Willson, 1982). The continuous measurements accumulated by SMM in 1980 are shown in Figure 1.4. It is obvious that the variations are not those of a white noise spectrum, but are well approximated by a steady background with minor rises and major, superimposed dips of varying amplitude. A similar radiometer on NIMBUS 7 spacecraft confirmed that these excursions, lasting one or two weeks, were real depletions of the solar constant. Moreover, they are associated with the appearance of sunspot groups and may be explained by blocking of the output by the sunspots. As the luminosity depletions last for several days to up to two weeks, one may conclude that the blocked energy does not appear in recognized form for time scales of at least months and probably years. This would indicate that the convective inhibition by the sunspots must be deep-seated in the convection zone.

It is evident from Figure 1.4 that the dominant dips which lasted approximately ten days would not have been resolved by measurements of the duration that can be provided by balloons or rockets, or even Space Shuttle flights. Had an isolated measurement been made during the period of such a dip, the result would have been misleading. Therefore, the continuity of the radiometric measurements appears essential here.

The precision of the SMM/ACRIM instruments is such that most, if not all, of the variance as given in Table 1 is solar, although its origin, especially in the range of minutes to several hours, is not yet understood in detail.

Table 1 Variance for different time scales from the SMM/ACRIM record.

time scale	variance
5 min	0.0003 %
1 hour	0.006 %
1 day	0.015 %
15 days	0.15 %
1 year	0.03 %

An obvious question is how these variations are redistributed within the spectrum. For periods of the order of hours and shorter, some information is available from balloon measurements (Fröhlich and Wehrli, 1982). Indeed, the colour ratios are changing from the 5 minute to the 1 hour range by about 50%: the ratio blue to red changes from 1:7 in the 5 minute to 1:10 in the one hour range.

The presence of a periodicity close to 24 days in the 250-day record of the SMM/ACRIM irradiance appears to be related to the reappearance of the principal solar active regions with near 24-day interval. With the caveat that any explanation of regular periodicity must be considered speculative, due to the limited amount of data, one might conjecture that there is a major locus of activity generation embedded in the convection zone which rotates at a period of 24 days (Willson, 1982). A time series of two years will provide a better test of this hypothesis.

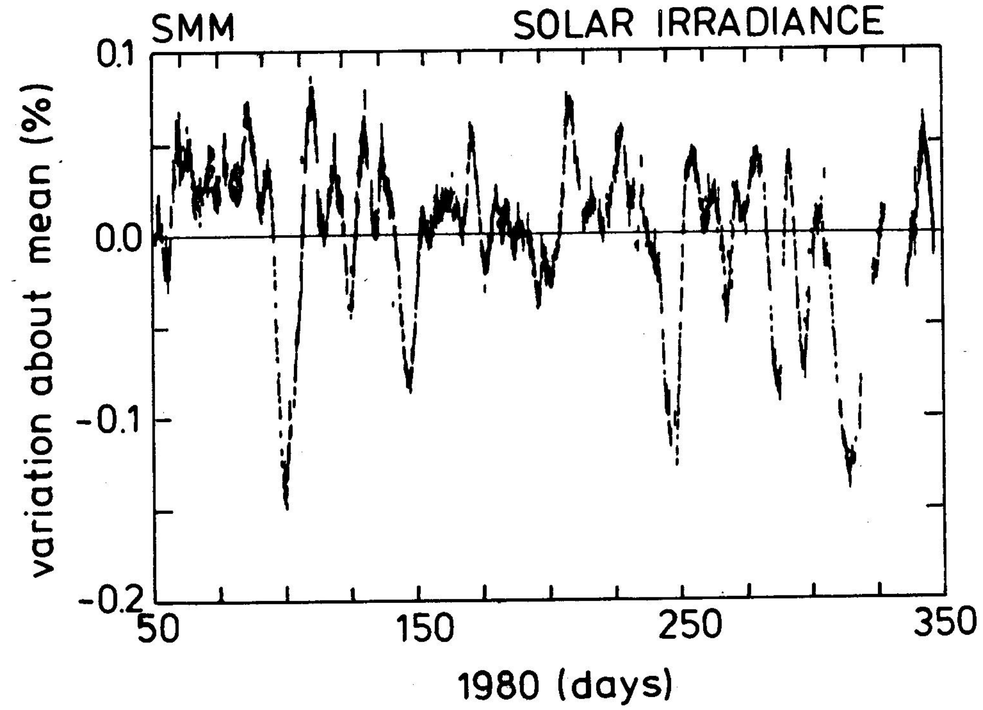


Figure 1.4 One AU total solar irradiance during 1980 derived from measurements by the SMM/ACRIM experiment, shown as percentage variation about the 1368.2 W/m^2 mean.

Time scales longer than months. The temporary decrease of the solar constant due to sunspot blocking leads one to conjecture that there may be longer-term luminosity variations associated with the 11-year activity cycle or the 22 years magnetic cycle. Already there is some indication of an increase of the solar constant from the late sixties to the eighties deduced from balloon, rocket and satellite data, which cannot just be explained by sunspot blocking. But the direct blocking of the radiation by sunspots is not the only process that can cause luminosity variations during the solar cycle. Variations in the mean magnetic stresses in the convection zone, changes in the efficiency of convection brought about by magnetic buoyancy, variations in the depth of the convection zone arising from the inhibition of convection in a boundary layer between the convective and radiative regions, all induce changes in the balance between thermal, gravitational and other forms of energy (Gough, 1982a). Such changes modify the hydrostatic structure of the Sun, and hence, lead to variations in luminosity and radius.

Limited theoretical computations suggest that the ratio of the variations in luminosity and radius associated with the cycle depends on the depth in the Sun of the perturbation that produces it. And if this is true, it seems likely that simultaneous measurements of luminosity and radius will enable us to decide how deep in the Sun the dynamo process operates. Radius measurements can be made from the ground, and a monitoring programme has already begun at the High Altitude Observatory in Colorado. Hill in the USA and Rösch at the Pic-du-Midi Observatory plan similar, though independent determinations. Accurate luminosity determinations, however, need irradiance measurements to be made from above the Earth's atmosphere.

Short- and long-term variation measurements of the solar irradiance are obtained in the DISCO payload with absolute radiometers and Sun photometers at different wavelengths. It is required that two different types of radiometers be on board to increase the reliability of the results with respect to ageing.

Observations of the global magnetic field

The Sun's magnetic field evolves with a 22-year magnetic cycle as a result of the interaction between solar rotation, convection, and magnetic fields. During the course of this cycle, new magnetic flux is generated by processes basically similar to those responsible for the magnetic fields of the Galaxy and the Earth. New flux emerges at the solar surface in statistically regular pattern, and old flux is annihilated or uprooted from the Sun.

Topologically, the Sun's magnetic field consists of two classes of structures:

- open field lines (which cause coronal holes), and
- closed field lines (trapping the heat flux and appearing as X-ray bright points and active-region loops).

When we observe the Sun as a star, the main contribution to the apparent net flux comes from the lowest-order harmonics, which are those linked to interplanetary space. This explains the strong correlation that is found between the mean solar magnetic field and the field measured in situ in the solar wind. Practically all (> 90%) of the magnetic flux, whether of open or closed topology, appears in extremely filamentary form in the solar photosphere, where the Zeeman effect is recorded. In the basic flux elements, the isolated fluxtubes, the field strength is 1 - 3 kG. On the average only 0.1 - 0.2% of the photosphere is covered by these sources of flux. Fluxtubes with a diameter > 1 Mm appear darker than the surroundings and are traditionally called sunspots, while smaller fluxtubes are brighter (facular and network points). The magnetic fields thus provide us with a unified view of widely different phenomena, whereby the primary variable is the fluxtube diameter. The degree of concentration of fluxtubes is determined by the properties of convection.

We can imagine the fluxtubes as local cavities of approximately cylindrical geometry having their own set of resonance properties with discrete frequencies. These cavities are embedded in a medium exhibiting the global oscillations. The oscillations act as external drivers of flux tube oscillations. As to which external modes the flux will respond is determined by their sub-surface structure.

Although the net magnetic flux does not change by these pulsations, the mean field polarisation signal will, nevertheless, exhibit such pulsations, since it depends not only on the magnetic flux but also on the concentration of the magnetic field. The amplitude and phase lag with respect to the velocity oscillations will depend on the details of the interaction between convection and magnetic fields, which is not well understood. Certain modes of the global oscillations are likely to resonate better with the magnetic fields than others, in particular those of larger periods. These oscillations should contain information on the variation with depth of the flux-tube diameter as well as on the maximum depth in the convection zone to which the field penetrates.

The "mean magnetic field" will also exhibit long-term variations mainly due to: solar rotation, pattern of flux emergence, pattern of flux removal (uprooting, annihilation) and field-line redistribution (global circulations, including giant cells and supergranulation). Periodicities in these processes have recently been discovered by Kotov and Levitsky. Instead of finding a broad power spectrum peak at the solar rotation period around 27 days, they find a large number of discrete spectral peaks around this period. Such discrete periodicities may provide basic information concerning the mechanisms of magnetic field generation in the Sun and the 22-year magnetic cycle.

The observations of the global magnetic field require a space platform such as DISCO, in order to provide long continuous time series free from atmospheric disturbances. Only from such a space platform would it be possible to correlate the fluctuations in the mean magnetic field signal with the corresponding fluctuations in the luminosity and the velocity signals. Such a concerted approach to oscillation spectroscopy wouldgreatly enhance the diagnostic value as opposed to recording these three oscillation spectra independently of each other.

Although it has not been included in the model payload, it should be stated that a compact, light-weight solar magnetometer using the Zeeman effect to record the mean magnetic field in the solar photosphere is feasible.

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1.3 PHYSICS OF THE HELIOSPHERE

By the heliosphere, we understand a single physical entity extending from its base at the Sun to form the interplanetary medium at 1 AU, and continuing out to the interface with the interstellar medium at many tens or even hundreds of AU. Observational techniques have in the past separated two regions for study:

- the corona, extending out to a few solar radii, studied by remote optical sensing
- the interplanetary medium at distances greater than 0.3 AU, which has been studied in situ but only in the ecliptic plane.

Between these two lies a region of transition which can presently be studied only indirectly. It is, however, a region of crucial importance, because it includes the principal region for solar wind acceleration, the change-over from quasi-thermal to non-thermal behaviour, and the region of morphological change from the solar to the interplanetary magnetic field configuration. Some of the outstanding problems in our understanding of the solar wind are associated with this region:

- the total solar wind mass flux and energy flux at 1 AU are nearly constant over many tens of solar rotations, despite the fact that the solar wind density, velocity and temperature vary considerably across the sector structure. This remarkable observation is clearly of great but ill-understood significance for solar wind theories, and leads to the next question
- what determines the observed speed of the solar wind at 1 AU ? Associated with this is
- what are the source regions of the solar wind? The fast-streams are thought to originate from coronal holes, large unipolar regions where the coronal magnetic field lines are open. However,
- where do the slow streams come from? Perhaps they also come from the coronal holes, but are they accelerated by a different process? But then
- why are there such sharp boundaries between fast and slow streams? Perhaps associated with this is the question
- why are there such large composition variations in the solar wind?

DISCO aims to study this important acceleration region of the solar wind by means of simultaneous coordinated observations of the regions on either side, using optical instruments on DISCO and wave and particle observations on both DISCO itself and on ISPM at high heliocentric latitudes.

A further objective of DISCO is to explore, in conjunction with ISPM (Figure 1.5), the three-dimensional structure of the heliosphere for the first time. At the time when ISPM was initiated, no specific plans were made for a simultaneous in-ecliptic mission, although the desirability of in-ecliptic observations was clearly recognised. It was expected that existing

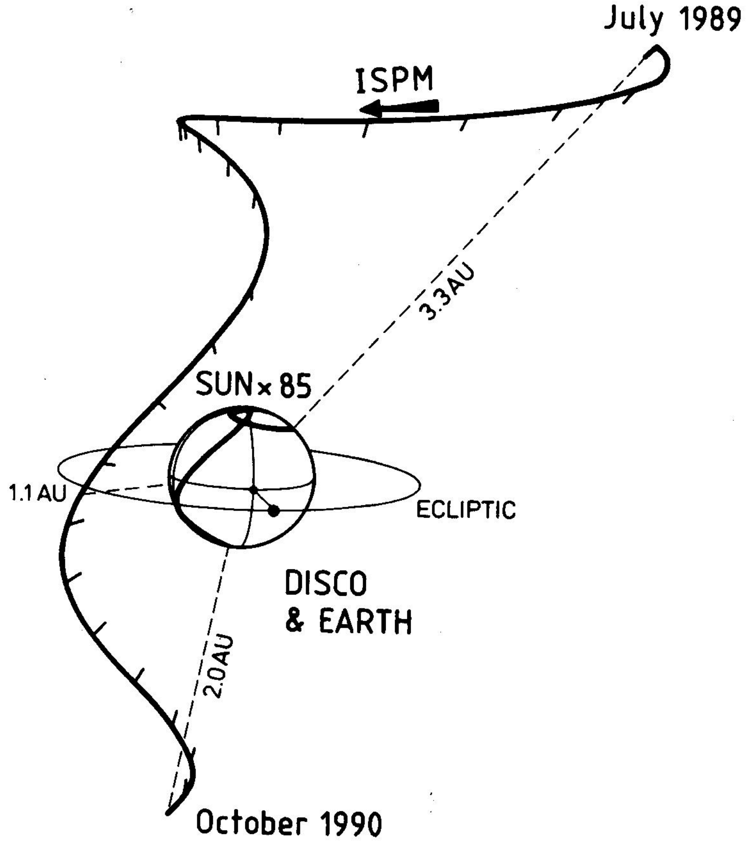


Figure 1.5 Relative trajectory of the ISPM spacecraft with respect to DISCO, and its projection on the Sun's surface, as seen from DISCO. The trajectory of ISPM depends on the choice of the initial polar passage being north or south, on the performance of the launcher upper stage and on the launch date. For the example a Centaur upper stage, a launch on 20 May 1986 and an initial northern pass has been assumed.

spacecraft, or spacecraft then about to be launched (in particular ISEE-3) would perform the necessary reference measurements. It was also anticipated that the out-of-ecliptic part of the mission would take place during solar minumum.

Both hypotheses have been invalidated by successive postponements of ISPM, and the high latitude passes will now occur in 1989-90, close to the next solar maximum. The expected complexity of heliospheric structures, as well as their greater variability in time will make the interpretation of high latitude data more delicate than anticipated, and simultaneous in-ecliptic measurements, rather than statistical models based on past in-ecliptic data, will be required to distinguish spatial and temporal features with any certainty. This need has been expressed by the ISPM Science Working Team in several resolutions. In the wider context, at the May 1982 COSPAR meeting it was proposed that the period 1988-90 should be designated as the "International Heliospheric Study", and a resolution was passed urging complementary observations at this time. This resolution was endorsed by the International Astronomical Union at its General Assembly in August 1982.

While the DISCO assessment study was in progress, the cancellation of the US ISPM spacecraft was announced. The effect of this was twofold: loss of the ISPM solar imaging experiment, and loss of a second spacecraft for correlative stereoscopic observations. These losses have dramatically increased the necessity for DISCO.

DISCO also offers the opportunity for new observations of the local, in-situ, solar wind. The originality for these observations lies in the orientation of DISCO, with one face permanently pointing toward the Sun, and in recent advances of instrument technology which enable the important physical parameters to be telemetered with much improved time resolution.

1.3.1 Solar Corona

Source region of the solar wind - the XUV corona and the white corona

Although the inner corona appears to be very complex, one can usually separate three different regions:

1. Those with mean field < 10 gauss which have closed field configurations. These one might call the "normal" quiet corona.

2. Those with mean field < 10 gauss which have field lines open to interplanetary space. These are the "coronal holes", which are also the source of the high speed solar wind, and

3. Small regions < 2 arcmin in extent with much larger fields and often complex field patterns. Here the heating and spectral emission is larger, but due to the small extent, their influence does not extend very far from the sun.

It is clear that whilst regions (1) and (3) are easiest to study, region (2) is of the greater importance to the interplanetary medium. The physical properties of coronal holes above 10^4 Km are very poorly known. Spectral lines of iron ions which concentrate predominantly above this altitude, could be crucial in removing these uncertainties, which have a direct bearing on the solar wind acceleration processes. Other important observations concern synoptic measurements of the boundaries between the open and closed regions, which are directly related to the interplanetary sector boundaries both in and out of the ecliptic plane.

It is perhaps surprising that such simple measurements have not already been made, since the techniques have been readily available for more than two decades. However, it is indeed the case, that through a variety of chance occurrences (the latest being the deletion of the XUV experiment from the SMM mission), such data have not been obtained.

Based upon the above considerations, one can define a set of requirements for an XUV instrument, in terms of the scientific demands and the performance. Time resolution need not be high, since the changes will be slow. Spatial resolution demands are also not severe for these scientific

Line	Å	Ionisation Sequence	T_e	N_e	$\int N_e dl$	$\frac{He}{H}$
Fe IX	171	✓				
Fe X	174	✓				
Fe XI	180	✓				
Fe XII	193	✓				
Fe XIII	204	✓				
Fe XIV	211	✓		✓		
Fe XIV	219	✓				
Fe XV	284	✓				
Fe XVI	361	✓				
O VI	150		✓			
O VI	1032					
H I	1216				✓	✓
He II	304				✓	
C II	1335	Instrument Scatter Monitor				

Table 1.2 Possible wavelength channels of a XUV spectroheliograph for DISCO and coronal information they would provide.

objectives and with 15 to 30 arc sec., the structural and physical characteristics of the coronal holes can be derived. However, the spectroscopic performance must be adequate to cleanly separate some close line pairs. Although the majority of existing spectral images of the corona are limited by being recorded in the weak coronal lines that occur at longer wavelengths, there are major advantages in exploiting the 150 Å to 500 Å region, since

a) the strongest lines of the abundant ion stages occur here, and

b) the cooler lower layers of the atmosphere do not emit in this region, thus avoiding the need for a coronagraph to limit scatter from the disc and allowing the corona to be observed above the disc.

But it is sensible to extend the upper wavelength limit so as to record the photo-excited 304 Å HeII and 1215 Å HI lines in order to measure the abundances of the two dominant chemical species, helium and hydrogen. For this reason also it is necessary to keep the instrumental scatter to a low level. A possible set of spectral lines is listed in Table 2. This shows also the range of physical parameters that could be derived. An ionisation sequence of iron lines can be used to plot temperature distribution on the assumption of steady-state balance. This assumption can be verified, corrected for, or the deviations interpreted, by a direct line-ratio electron temperature measurement. Other line-rations give intrinsic electron density measurements. Measurements of the helium and hydrogen lines give line-of-sight density integrals as well as abundances.

An *XUV imaging spectrometer* such as the one included in the model payload not only is capable of producing simultaneous images of the corona in several spectral lines but also permits at the same time diagnostics of the physical properties of the coronal plasma.

For the inner corona, a white-light coronagraph can give important morphological data, and extend the region of optical observations from 2 $R_\odot$ to 15 $R_\odot$. While such an instrument has not been included in the current model payload, its inclusion at the time of instrument selection could be envisaged, with a corresponding impact in the scientific return from the DISCO mission. Coronagraphs are well suited to study transient events, mass ejections and solar activity phenomena occurring at all solar latitudes, and strongly influencing the interplanetary medium. White light pictures can also yield precise data on interplanetary sectors and their boundaries, vertical extensions of coronal holes and precise large scale geometry of the field lines. For instance, an externally occulted coronameter could take advantage of the rotation of DISCO to scan the external corona.

Anisotropy and height distribution of solar X-ray emission

Hard X-ray photons carry the most direct information on the energetic electrons accelerated in solar flares. They reach the observer without being affected by propagation effects and are produced by a well known emission mechanism, i.e. bremsstrahlung from energetic electrons. Nevertheless, we still do not know the nature of the velocity distribution function of the electrons emitting X-rays. We know neither the height at which the acceleration takes place nor the physical conditions in X-ray sources.

The fact that the X-rays propagate in a straight line and are most frequently emitted in discrete events can be used to locate their origin and to obtain their emission angular distribution by simultaneous observation from two widely separated spacecraft. The original 2-spacecraft ISPM was considered to be a unique occasion for the study of solar X-ray (10 - 100 KeV) sources with two identical instruments. The cancellation of the NASA spacecraft has reduced the scientific potential of the experiment. A flight of the second instrument on DISCO would recover all the science return.

1.3.2 The Solar Wind and Heliospheric Structure

Past observations of the interplanetary medium have been made exclusively from spacecraft situated within or close to the ecliptic plane. Nevertheless, a picture has emerged of a heliosphere with three dimensional structures, within which the ecliptic plane occupies rather a special position, being simultaneously perpendicular to the solar rotation axis and also close to the equatorial plane of the large scale solar magnetic field.

The contribution of DISCO to the study of heliospheric dynamics is multiple:

- measurement of the latitudinal gradient of solar wind bulk plasma parameters as ISPM moves out of the ecliptic and towards high heliospheric latitudes.

- investigation of the large scale structure of the heliospheric magnetic field using correlated magnetometer observations between DISCO and ISPM for local sensing, and radio techniques for remote sensing of the field.
- comparison of wave particle interactions observed simultaneously in the very different solar wind flow regimes in the vicinity of DISCO and ISPM.
- study of the latitudinal extent of coronal mass ejection events and their associated shock waves by means of correlated DISCO/ISPM observations.
- correlation of the solar wind observed at 1 AU by DISCO and at high latitude by ISPM with coronal far-UV observations of the solar disc, the latter including the source regions of the observed solar wind.
- high time resolution of solar wind particle distributions, making use of DISCO's sunward pointing face.
- solar wind composition measurements, exploiting recent advances in instrument technology.

The solar wind

The exploration of the solar wind during the past two solar cycles by spacecraft making a variety of in situ observations close to the ecliptic plane, has confirmed the existence of an outward flowing supersonic plasma and of a spiral-shaped magnetic field structure. Except during the inversion phase of the solar magnetic cycle, the heliospheric magnetic field resembles a dipole deformed by the expansion of the solar wind; fields from the unipolar coronal holes are dragged out and separated by a vast neutral sheet lying more or less in the ecliptic plane. Owing to the asymmetry of the coronal holes and their evolution throughout the solar cycle, this neutral sheet oscillates in latitude as shown in Figure 1.6 and gives rise to the sector structure. The small inclination of the solar equator to the ecliptic (7°) means that our view of the interplanetary magnetic field is conditioned by the proximity of the current sheet. The brief excursion of Pioneer XI to 17° heliocentric latitude has shown that even at moderate latitudes the sector structure can weaken considerably.

Spatial irregularities are impressed upon the solar wind flow by the superficial variations of the solar corona, and give rise to outwardly convecting streams of differing flow velocity. The magnetic field is frozen into the plasma and convected along with it, thus leading to the familiar spiral mean magnetic field model with plasma on the same magnetic field line originating from the same coronal source. Close to the Sun, where the field is nearly radial, the different streams slip past each other, but further out, where the spiral angle becomes tighter, the faster streams inevitably run into the slower streams ahead of them. The relative flow being both supersonic and super-Alfvenic, the resulting discontinuity becomes flanked on each side by an outward propagating shock wave, the ions. In particular, the abundance of ^{4}He is lower than the best estimates of its coronal abundance. This could be caused by the low ionisation rate of helium, which gives a Coulomb collision cross-section low enough for it not to be strongly coupled to the accelerating solar wind plasma. This marginal coupling would then be indicative of different conditions in the source regions of low speed streams. The abundance of ^{4}He will be measured by the plasma analyser. Observations of heavier elements are too scarce to know whether there are any systematic variations of their abundances. A thorough study of the abundances of several ions is needed to help describe the low speed solar wind source regions.

The ultimate aim of measuring the composition of the solar wind is to relate it to solar composition, fractionation processes in the solar atmosphere and wave-particle interactions in interplanetary space. The measurement of the ionisation states of solar wind ions can provide information on the temperature profile in the corona. The altitude at which the ionisation state is frozen-in is different for different ions. A new generation of instruments for measuring separately the mass and charge of the solar wind ions is now being developed. Such an instrument has not been included in the model payload, but it would complement the solar wind composition experiment on board ISPM.

Shock waves

Almost all collisionless shock waves observed in the solar wind at 1 AU are thought to be related to coronal mass ejection events. Plasma observed immediately after the shock passage is compressed ambient solar wind, and this is followed, when the geometry is favourable, by the coronal ejecta, which can be recognised by anomalous abundances, ionisation states, and/or anomalous proton or electron distributions. The mass ejection is not necessarily radially outwards, and the shock wave propagation through interplanetary space is severely distorted by the solar wind sector structure. This will be studied by simultaneous observations from DISCO and ISPM, as will the associated energetic particles, discussed below.

1.3.3 Energetic Particles in the Heliosphere

Energetic particles give us information about physical processes in the region where they are accelerated. The value of this information depends upon the extent to which we can identify the source regions, and seperate source and propagation effects insofar as this is possible. Study over many years has shown that propagation through the heliosphere strongly influences the temporal, spatial, energetic and compositional characteristics of the measured particle fluxes, but that different sources can, nevertheless, be clearly identified, such as solar flares, interplanetary shock waves, corotating interaction regions, and the Galaxy outside the heliosphere. Current research aims at obtaining as good an estimate as possible of the corresponding source functions, including the energy and composition distribution, and the time evolution when appropriate. A complementary aim is a better understanding of propagation effects, which are related in turn to the structure and turbulence in the heliosphere.

DISCO can make a twofold contribution to this effort. The correlation of energetic particle measurements aboard space probes at different locations in the ecliptic has often been used to help distinguish between temporal and spatial effects, resolve the longitudinal and radial characteristics of energetic solar particle events, and determine the cosmic ray radial gradient. The advantage of having energetic particle measurements from DISCO when ISPM will be exploring the high latitude heliosphere is developed below.

Secondly, energetic particle propagation is intimately related to both local and remote heliospheric turbulence levels; appropriately, turbulence will be measured on both DISCO and on ISPM. Therefore we shall obtain correlated particle observations with simultaneous detailed wave turbulence measurements at two very different points in the heliosphere.

Energetic particle propagation

The propagation of energetic particles in the heliosphere, whether of solar, interplanetary, or galactic origin, is determined by their interaction with the magnetised solar wind plasma. Propagation is usually described in terms of diffusion along magnetic flux tubes being convected in the solar wind, adiabatic deceleration due to the diverging flow of the solar wind, and focusing along the divergent magnetic field lines.

Solar flare associated particles of energy greater than a few MeV usually show characteristic diffusive intensity-time profiles at 1 AU. The diffusion coefficient and its energy dependence have been derived from the measured profiles, yielding mean free paths in the range 0.1 to 1.0 AU or even greater. However, mean free paths calculated from the observed magnetic field fluctuations are about an order of magnitude smaller. This disagreement suggests that theroretical models, particularly in their normally used quasi-linear form, need some revision. A closer study of the nature of the scattering properties of waves and magnetic field irregularities is required to remove the discrepancy between observations and theory.

The propagation of cosmic rays in the heliosphere is essentially a three-dimensional process. In the past few years the role of curvature and gradient drifts in the large scale heliospheric magnetic field has been reassessed, leading to new models of solar modulation, based on the 22-year solar magnetic cycle. While the dominant role assigned to drifts in these models has not been generally accepted, the argument has highlighted the need for good three-dimensional models of the heliosphere. The first, and perhaps only test of three-dimensional propagation models will be provided by ISPM, assuming that adequate reference measurements, such as those proposed on DISCO, are available in the ecliptic plane.

Flare associated energetic particles

Energy from solar flares leaves the flare site in the form of a shock wave driven by an expanding mass of coronal material, and it is likely that such shock waves are responsible for most of the features of solar energetic particles observed in interplanetary space. The fraction of the energy in the form of energetic particles, and the observed energies, up to several hundred MeV, point to the existence of remarkably efficient acceleration mechanisms, which are at present only poorly understood.

Multi-spacecraft measurements have shown that the injection function, including both acceleration and coronal propagation, resembles a fast rise followed by an exponential decay, with an energy and/or rigidity dependent time constant of the order of one hour. The mechanism of coronal propagation and escape onto interplanetary field lines is not known; the diffusive model normally considered is propably a gross oversimplification. Detailed observations of the corona made simultaneously with particle observations at a number of points in space are required to establish a synoptic model of coronal propagation.

The energy spectrum and composition of solar particles are important indication of the nature of the acceleration mechanism and of the region of the solar atmosphere where acceleration takes place. Considerable variations in elemental composition can be seen from event to event. Some of the anomalies in measured abundances are probably related to the observed dependence of these anomalies on first ionisation potential. However, it is not known whether the acceleration mechanism itself is selective, or whether the anomalies arise from selective transport processes in the solar atmospheren.

The instrumentation on board DISCO should measure the intensity and three dimensional anisotropy of flare associated electrons, protons and α-particles, as well as the elemental and perhaps isotopic composition, as a function of energy.

Interplanetary acceleration of energetic particles

Carefully correlated analyses of particle anisotropy data with local plasma parameters have shown that interplanetary shock waves and their immediate neighbourhood are sources of accelerated particles. Similarly, gradient measurements between spacecraft at 1 AU and at larger heliocentric distances have shown that as CIR's develop beyond 1 AU, an excess particle flux is formed between the forward and reverse shocks. It has proved surprisingly difficult to model the acceleration process, but, because of their wider astrophysical significance, these studies are being very actively pursued.

In order to discover further details of the acceleration process, it will be necessary to perform detailed measurements on low energy ion fluxes in the tens of KeV/nucleon energy range. While such measurements are at present beyond the capabilities of the instruments in the model payload, alternative instruments may well be able to contribute to this currently active research field. However, even without further refinements in the proposed instrumentation, correlated observations with ISPM are certainly expected to bring new information on the latitude dependence of interplanetary acceleration.

Cosmic rays

Cosmic rays convey important information on astrophysical processes occurring in and close to their source regions, as well as on the structure and evolution of the Galaxy. They also are an indication of conditions in the most distant parts of the heliosphere, information which is difficult to obtain by any other means. The separation of the influence of propagation effects on the observed fluxes is, however, a rather delicate problem, and there is still no satisfactory answer to the question: what is the basic mechanism of solar modulation?

A considerable quantity of data is now available on solar modulation effects. There is good coverage of the last solar cycle, including observations of the onset of the current modulation cycle in 1978, from widely separated heliospheric distances in the ecliptic plane. The greatest achievements were the measurement of the cosmic ray density gradient in the ecliptic over a large range of heliocentric distances, and the observation of modulation effects to 25 AU. These measurements were made possible by simultaneous observations from the Pioneer and Voyager spacecraft far from the Sun and by a series of near-Earth spacecraft at 1 AU.

Similar important results are expected from ISPM concerning the latitude dependence of modulation, provided that in-ecliptic reference measurements are available.

In order to provide the required measurements, the instrumentation on board DISCO can be relatively simple, covering the intensity and anisotropy of the most abundant components of cosmic rays.

The behaviour of cosmic ray electrons is differentiated from that of cosmic ray nuclei by their negative charge and their much lower rigid (momentum/charge). Most of the low energy (< 25 MeV) electrons observed in the ecliptic are of Jovian origin. This situation may well change at higher solar latitudes, although confirmation of this by ISPM, supported by in-ecliptic reference data, is still required.

The anomalous component

A rather special problem arose with the discovery of the so-called anomalous component of cosmic rays. This consists of an appararent excess of He, C, N and O nuclei above their expected abundance in the 10-50 MeV/n energy range. There is some controversial indirect evidence to suggest that, unlike other cosmic ray nuclei, the anomalous component consists of partially ionised nuclei. The controversy is unlikely to be settled before direct measurements of the charge state of these nuclei become available. Their origin is unknown, although it has been suggested that the anomalous component is formed from neutral atoms penetrating the heliosphere from interstellar space: after being ionised by solar radiation, the particles are swept out to the distant heliosphere where they are accelerated stochastically.

The interest of the anomalous component lies in its rather special signature and sensitivity to modulation, which may provide clues to heliospheric processes acting on the whole cosmic ray population.

An instrument capable of measuring the elemental composition of cosmic rays in the relevant 10 - 50 MeV/n energy range, is included in the model payload.

1.4 OTHER SCIENCE FROM THE SUN - EARTH LAGRANGIAN POINT L1

The attitude and location of DISCO, Sun pointing spinning platform at the Sun - Earth L1 Lagrangian Point, offer new possibilities for scientific experiments other than those related to purely solar or heliospheric measurements described in the two previous sections. The following scientific objectives are among those that could be achieved with appropriate instrumentation aboard DISCO. Although only one of them is included in the model payload, they are all potential candidates, with strong interest by European groups.

Micrometeoroids

The distribution of dust in the solar system will be determined with the help of detectors aboard ISPM and the Galileo spacecraft, and it would be much more complete if a baseline mission (like DISCO) could obtain simultaneous measurements with them at 1 AU. Correlation between the three spacecraft would allow us to understand the dynamics, large scale structure and evolution, including solar cycle effects on interplanetary micrometeoroids as well as to facilitate the in situ detection of interstellar grains.

Lα observations of comets in the vicinity of the Sun

Lα observations of comets over the last decade showed that hydrogen is the most abundant species in comets. Most of it is produced in the cometary coma by dissociation of H_2O. Close to the Sun the Lα emission of the central parts of the hydrogen coma become very bright. The size of a comet in the vicinity of the Sun will be determined by the scale-length of hydrogen $\gamma H = \tau H$. 20 km s^{-1}, which is 4 x 10^5 km for $r = 0.1$ AU.

Systematic Lα observations in the solar vicinity will allow the observation of all comets without discrimination according to their size, including the faintest, i.e. smallest cometary nuclei. This makes it possible to determine the mass (and size) distribution of cometary nuclei, including those at the lower end. The statistics of observations will give us valuable clues about cometary origin and their evolution.

Interstellar gas diagnostics from the heliosphere

The DISCO orbit, outside the geocorona, is particularly suitable to study the neutral components in the interplanetary medium.
Neutral species of the local interstellar medium (LISM) have good chances to traverse the heliospheric plasma interface and penetrate into the inner part of the heliosphere. According to their density and velocity distributions there, these species (mainly H and He, probably also O and Ne) resonantly scatter solar photons and produce specific luminescences in interplanetary space. The theoretical interpretation of these luminescence patterns on the basis of appropriate LISM-models has been recognised as the most promising technique to infer the relevant LISM parameters as: T_H, T_{He}, n_H, $\vec{v}_{LISM}$, X_{LISM}, i.e. the hydrogen and helium temperatures and densities, the LISM wind velocity and ionization degree. However, the current interpretations of HI-Lyman-α and HeI 584 A-resonance isophotes with the help of conventional LISM-models have led to some physically inconsistent results.

The dilemma could be perhaps solved by a systematic observation of HI-Lyman-α and HeI 584Å resonant radiation from DISCO. Connected with a continous monitoring of the solar emission, if possible with resonance-spectrophotometric information on the emission profiles, one would for the first time be able to confidently and unequivocally interprete resonance radiations that are observed at the same time.

Another technique could be used to study the LISM: Direct detection of the neutral H, He and minor species (such as ^{3}He, ^{13}C, ^{20}Ne, ^{22}Ne) would provide new data, less dependent on modelling assumptions than the radiation backscatter. A neutral mass spectrometer would significantly increase the value of measurements done on ISPM by allowing the study of the gradients across the heliosphere.

Identification of gamma ray burst sources

A decade after the discovery of gamma ray bursts, their origin remains unknown. There is only one approach which is certain to lead to significant progress: the localisation of burst directions to precisions compatible with optical astronomy. To localise the source of emission on the celestial sphere to an accuracy of better than one arc minute using the triangulation method, three or more widely separated spacecraft are needed. Past experience has shown that the use of identical detectors greatly simplifies the interpretation of the data.

A solar X-ray and cosmic gamma ray burst detector will be aboard the ISPM spacecraft. A twin instrument was to be placed on the NASA ISPM spacecraft, in order to provide very long baseline observations of cosmic gamma ray bursts, and stereoscopic observations of solar X-rays (section 1.3.1). That instrument has now been included in the DISCO model payload. The remaining solar polar spacecraft will still provide the longest baseline ever achieved in this type of investigation, and will also provide the most favourable geometry between the various spacecraft, since it is out of the ecliptic plane. The resulting accuracy will therefore exceed that of present measurements by more than a factor of three throughout most of the mission.

Stellar seismology

In its present design the DISCO spacecraft will make use of the star Canopus (α Car) in order to provide a phase reference to its rotation. This star is commonly used for its brightness and because it stands close to the ecliptic pole. Being a Fo Ib star it can be expected - as all the supergiants - to be slightly varying with an amplitude of a few hundredths of a magnitude and with a semi-period which could range between 20 and 80 days. Its brightness makes it difficult to observe with the usual photon counting systems, even with small telescopes.

It is proposed as a serendipity experiment that the flux reaching the star tracker be integrated over the time of Canopus visibility and that this information (corresponding to a sampling of Canopus flux every spin revolution) be transmitted to the ground on standard telemetry. The length of the observing time (two years) should allow the determination of the time scale of the variations which is necessary to determine the excited mode.

1.5 SUMMARY OF SCIENTIFIC AIMS AND MEASUREMENTS REQUIRED

Table 1.3 summarises the scientific objectives of DISCO that have been described in the previous sections, the measurements that would achieve them and some of the instruments so far proposed by European research groups to perform the measurements. The instruments marked with an asterisk have been used during the Phase-A study as representative of the DISCO payload, as will be discussed in next chapter.

A dominant feature of DISCO is its integrated design. Many of the scientific aims of DISCO will be achieved by the combined analysis of several simultaneous measurements. For instance:

- Information on solar dynamics of the upper layers of the convection zone will be obtained by the study of the relative phases and amplitudes of global velocity and luminosity oscillations.

- The different sources of the solar wind will be studied by comparing "in situ" plasma analyser measurements with spectrographic information of the XUV corona.

- The coronal structures observed in the spectroheliograms will provide the link to understand the gradients between ISPM and DISCO, across part of the heliosphere, that will be measured by the fields and particles experiments.

Table 1.3 DISCO: Aims and Potential Instrumentation

DISCO SCIENCE: The Global Sun - Solar Interior Diagnostics

Scientific Aims	Measurements	Instrument	P
Helioseismology - solar stratigraphy - internal rotation - quadrupole moment of the Sun (J_2)	Frequencies, amplitudes and phases of velocity oscillations, phase coherence and amplitude variations - resolution 1 mm/s	High resolution spectrometer (Doppler measurements with alcaline vapour resonance cell) High resolution spectrometer (Fabry-Perot interferometer)	*
	Frequencies, amplitudes and phases of solar luminosity oscillations - relative precision 10^{-6}	Solar irradiance	
Convection zone dynamics and thermal properties - photospheric redistribution of energy	Total and spectral irradiance variations (minutes to years) - short term relative precision 10^{-6} - long term absolute accuracy 10^{-3}	- Photometers operating in narrow wavelength band windows - Absolute radiometers	* *
Solar magnetic field - Penetration of fluxtubes in convection zone.	Frequencies, amplitudes and phases of global sun magnetic field oscillations.	Michelson interferometer (Zeeman effect)	

* Refers to instruments of the model payload

Table 1.3 Cont'd.

DISCO SCIENCE: Physics of the Heliosphere

Scientific Aims	Measurements	Instrument	P
Solar Corona - source region of the solar wind - solar cycle evolution of coronal structures	Large scale temperature and density distribution in the corona - spectrum 15-135 nm with 0.03 nm resolution and 0.5 arc min spatial resolution	Far ultraviolet spectroheliograph (imaging the Sun up to 1.5 $R_\odot$ in 12 spectral lines simultaneously)	*
- magnetic field structure - mass ejections	White light coronal observations > 2 $R_\odot$	Coronameter	
- electron acceleration and propagation in solar flares	Solar X-rays source height evolution and angular distribution (simultaneous with ISPM)	X-ray detector	*
Solar wind	Solar wind magnetic field at 1 AU	Magnetometer	*
- 3-dimensional structures of solar wind features	Solar wind composition and velocity distribution functions	Plasma ion and electron analyser.	*
- solar wind plasma fine structure	Solar wind plasma wave turbulence. Evolution of solar type-III radio burst (simultaneous with ISPM)	Electro magnetic wave experiment covering 10 Hz to 1 MHz	*
Energetic particles - particle acceleration and propagation mechanisms in the heliosphere.	Solar particle composition, energy spectra and directional distributions Galactic cosmic rays composition, energy spectra and directional distributions	Energetic particle detectors	
		- Low energy particle directional spectral analyser	*
		- Medium-to-high energy particle telescope system	*

* Refers to instruments of the model payload

Table 1.3 Cont'd.

DISCO: Other Science from the Lagrangian Point L_1

Scientific Aims	Measurements	Instrument	P
Micrometeroroids - solar system dust distribution	Mass spectrum of micrometeoroids simultaneous with ISPM	Dust impact detector	
	Zodiacal light	Zodiacal light detector	
Comets distribution	Ly-α coronal observations	Ly-α coronagraph	
Local interstellar medium - properties and interaction with heliosphere	Neutral H and He density in inner heliosphere		
	- H Lyman-α and He I 584 Å resonant scattered light	H Lyman-α and He I 584 Å cells	
	Mass spectrum of neutrals	Mass spectrometer	
Cosmic γ-ray bursts - source location	accurate timing of γ-ray burst and time relation with other spacecraft	γ-ray detector	*
Stellar oscillations	Canopus luminosity variations	Star sensor	

* Refers to instruments of the model payload

2. MODEL PAYLOAD AND MISSION REQUIREMENTS

2.1 PAYLOAD

The final DISCO payload will be selected as the result of an Announcement of Opportunity after approval of the mission. For the Phase-A Study a model (or study) payload was established with two aims:

- to quantify the requirements and resources of the payload so that a realistic spacecraft can be defined
- to demonstrate that instruments exist that can cover a large fraction of the scientific objectives described in the previous sections with the proposed DISCO spacecraft.

All instruments proposed are feasible without major new developments. Several instruments have been developed for other spacecraft - specifically the heliospheric physics instruments. The solar irradiance package and the far-UV spectroheliograph are derived from instruments developed for balloons, rockets or Spacelab. The high resolution spectrometer, that so far has operated only on the ground, underwent a Phase-A Study to prove its feasibility of operating in space.

Table 2.1 lists the experiments included on the model payload together with their resources, field of view and pointing/mounting requirements.

2.2 MISSION REQUIREMENTS

The following main requirements for the spacecraft design have arisen from the model payload:

Operation

Continuous, uninterrupted measurement during two years is required by the high resolution spectrophotometer and the solar irradiance measuring instruments, because they perform measurements based on time series analysis and the achieved resolution depends on the absence of data gaps.

Field of view and pointing

- 8 instruments need to have the Sun in their field of view
- 4 experiments need to be pointed to the centre of the Sun within 0.6^0 at all times (continuously).
- the FUV experiment needs to be pointed to the centre of the Sun within 5 arc minutes for at least 2 hours every day, to produce solar images with a simple guidance system, and using the spin of the spacecraft for scanning.

Velocity in the Sun direction

To reach the required sensitivity in the measurement of solar velocity oscillations by the high resolution spectrometer no sudden changes of the velocity of its optical centre in the Sun direction must occur with an amplitude larger than 1 mm/s. If unavoidable, they must be measured with a precision better than 1 mm/s. This requirement affects mainly the attitude and orbit manoeuvres and demands a careful dynamical study of the spacecraft movements.

Table 2.1 MODEL PAYLOAD

Experiment	Mass (Kg)	Average power (W)	Telemetry (b/s)	Special Requirements
High Resolution Spectrophotometer (HRS)	21	20.5	15	Pointing to Sun centre within 0.6°. S/C velocity in Sun direction smooth within 1 mm/s. Continuous data coverage. Spin phase known within 2 arc min.
Absolute Pyrheliometer (APH)	5	6.5	5	Pointing to Sun centre within 0.6°
4-Channel Absolute Radiometer (AR4)	7	13.3	3	Pointing to Sun centre within 0.6°
6-Channel Sun-Photometer (SP6)	6.4	14.0	14	Pointing to Sun centre within 0.6°. Spin phase known within 2 arc min. Continuous data coverage.
Far UV Spectroheliograph (FUV)	26	40	100	Pointing to Sun centre within 5 arc min during 2 hours every day. Pointing stability better than 10"/min.
Magnetometer (MAG)	2.3	3	80	Boom mounted (> 2 m) for EMC
Radio Wave Receiver (RWR)	4.4	3	30	72 m tip-to-tip wire boom antenna
Plasma Wave Analyser (PWA)	3.8	4.6	80	Boom mounted (∿ 2 m) for EMC
Solar Wind Ion Analyser (SWI)	4.5	4	100-400	Sun in field of view. FOV: 45° cone.
Solar Wind Electron Analyser (SWE)	1.2	1.5	50-100	Sun in field of view. FOV: 130° x 8°
Low Energy Particle Directional Spectrum Analyser (LEP)	4.7	5.5	80	4 telescopes pointing at 30°, 70°, 110° and 150° to spin axis. FOV: 30° cone.
Medium to High Energy Particle Telescope (HEP)	6.0	7.0	100	2 detectors pointing at 90° to spin axis. FOV: 90° and 60° cones.
Solar X- and Cosmic γ-ray Burst Detectors (XGR)	1.9	2.6	40	Boom mounted to achieve 4π FOV and for thermal control. Universal time known within 2 ms.

3. LAUNCH AND ORBIT ANALYSIS

3.1 System Constraints

For cost control reasons the DISCO spacecraft has been constrained to a dual launch with Ariane II, coupled with the use of a single ground station during the operational phase. The use of an Ariane launcher means that DISCO will initially be injected into a Geostationary Transfer Orbit (G.T.O.).

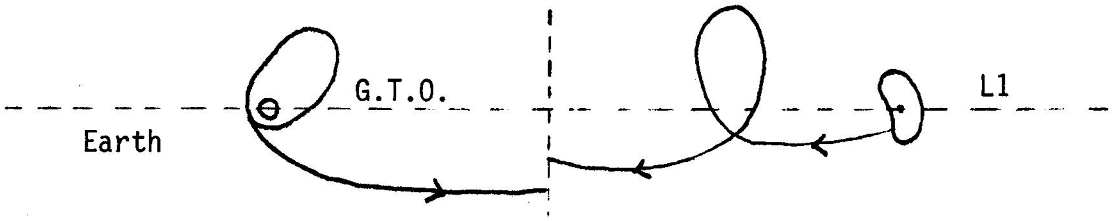
Regarding the operational orbit the payload requirements were initially evaluated for sunsynchronous, geosynchronous, libration point (L1) and earth-like orbits. The latter two orbits met all requirements but the earth-like orbit was eliminated because of its impact on spacecraft complexity (with respect to communications). It is interesting to note that only one spacecraft (ISEE-C) has ever previously been placed in an L1 orbit.

3.2 Orbit Analysis

The orbit analysis has to consider:

i) Ariane launch placing the spacecraft in G.T.O.
ii) Transfer orbits from G.T.O. to L1
iii) The form of the final orbit at L1

Regarding calculation of transfer orbits it should be noted that the libration point presents a particular challenge. This is essentially because we are dealing with a 3-body problem in the vicinity of L1 and hence a "conventional" approach (such as that using patched conics) is not valid. Furthermore the very high sensitivity of the orbit to small parameter changes in the region of L1 means that a full optimisation of the transfer trajectory could not be performed in the timescale of the study. Instead an approximate approach based on an iterative procedure was employed. Essentially this consisted of choosing a given orbit at L1 and working the trajectory "backwards" from an insertion point, while working the initial part of the orbit "forwards" from the G.T.O. This is illustrated in the following sketch:



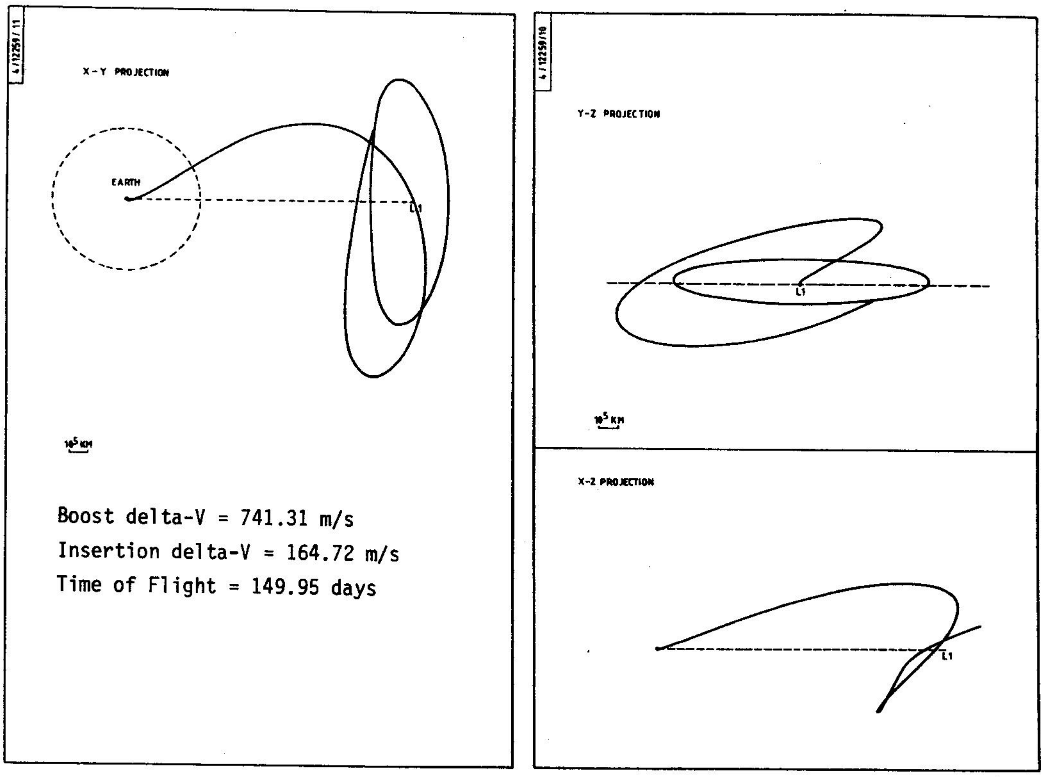
Intermediate "matching" plane

The iteration procedure is used to find an intermediate point where both parts of the orbit meet, the trajectories being a function of 9 variable parameters. For the actual programming only 5 of these parameters were chosen to be variable since the trajectories were founded to be relatively insensitive to the remainder.

The five significant parameters are:

1) magnitude of injection
2) local time of GTO perigee
3) magnitude of retro manoeuvre
4) Z-component of retro manoeuvre
5) X-component of retro manoeuvre

An example of such a trajectory is shown in Figure 3.1.

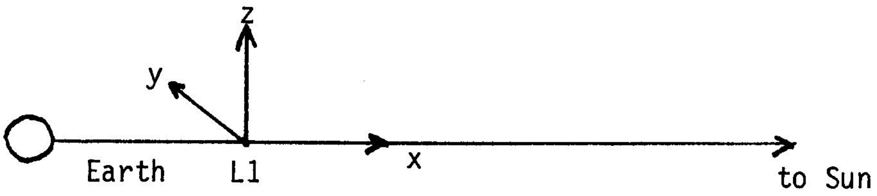


Boost delta-V = 741.31 m/s
Insertion delta-V = 164.72 m/s
Time of Flight = 149.95 days

Fig. 3.1 Sample Cruise Trajectory from GTO to Halo Orbit

The cruise phase to L1 has a duration of 90-150 days depending on the time of year at which the launch takes place. Fast transfers (approx. 35 days) also exist but have been rejected for DISCO because of the extra delta-V needed and constraints imposed by the dual launch.

A so-called halo orbit around the L1 point has been chosen for DISCO's operational phase as was done for ISEE-C. Some background is necessary in order to explain this orbit. First we define an orthogonal axis set in the ecliptic at the L1 point as shown in the sketch below:



The L1 Lagrange point is a theoretical point where if a body of negligible mass is placed at rest it will remain at rest. The distance d is measured from the earth-moon barycentre and is, approximately 1.5 x 10^6 Km. To insert a spacecraft exactly at the L1 point takes a lot of energy and, besides, it would then not be possible to communicate with the satellite from the earth because of the interference from solar radio noise. For this reason an orbit around L1 with at least a 2° amplitude as seen from the earth (i.e. in z-y plane) is required. Such an orbit is not stable and therefore requires some station-keeping. In general terms the larger this amplitude the lower is the insertion energy required. Furthermore such an orbit around L1 generally describes a Lissajous figure (see dia. 3.2 (a)). The halo orbit is a particular case of the Lissajous orbit where the movements in the Y and Z planes are in phase and where the Y and Z amplitudes are related by the following equation:

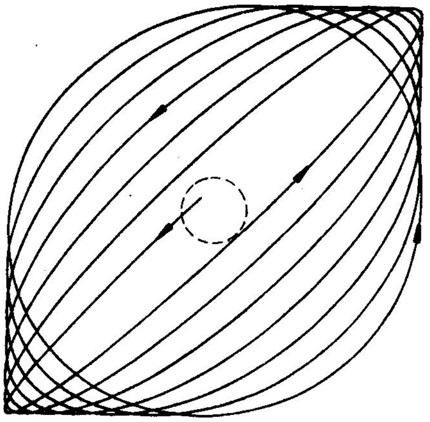
$$k_1 A_z^2 - k_2 A_y^2 + k_3 = 0$$

where $k_1 = 1.89\text{x}10^{-13}$; $k_2 = 1.66\text{x}10^{-13}$; $k_3 = 0.07$;

and A_y and A_z are in kilometers.

In this case the minimum possible Y amplitude is $6.5\text{x}10^5$ km in order to achieve a halo orbit. From the point of view of the spacecraft the maximum amplitude allowable is a function of antenna performance and for DISCO this is limited to around 10^6 km. The shape of such a halo orbit is shown in Figure 3.2 (b) (both in Y-Z and X-Y planes).

Fig. 3.2 a)



LISSAJOUS ORBIT

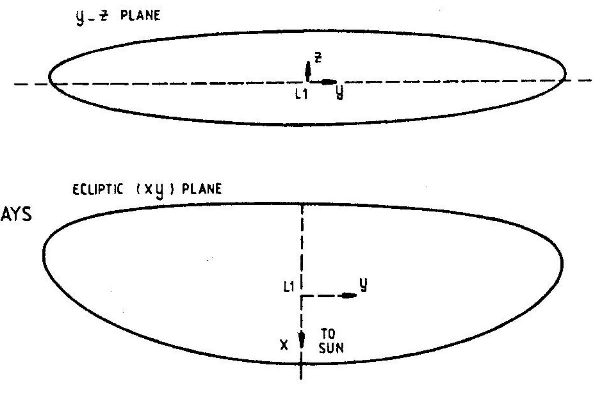
A_z = 330.000 km.

A_y = 330.000 km

2° EXCLUSION ZONE

SHOWN FOR 3 YEARS

Fig. 3.2. b)



HALO ORBIT

A_z= 120.000 km.

A_y= 667.000 km.

PERIOD 177.71 DAYS

For such an orbit the spacecraft is never in eclipse. The parameters chosen for the DISCO halo orbit are $A_z = 12 \times 10^4$ km, $A_y = 66.7 \times 10^4$ Km and period = 178 days. Larger amplitudes cannot be used due to beamwidth limitations of the on-board antenna.This orbit has a number of advantageous features for DISCO viz.:

- low injection delta-V
- relatively infrequent stationkeeping manoeuvres
- relatively low absolute velocity in the sun direction
- back-up experience of ISEE-C can be used thus giving higher confidence in computational methods
- spacecraft can be always sun facing and always remains in the solar wind
- spacecraft permanently outside the 2° exclusion zone.

A particular feature of the mission is that the sun will drift with respect to the spacecraft viewing direction at a rate of 1° per day. The mission is arranged such that at the beginning of the 24 hour period the spacecraft points 0,5° away from the sun centre in the ecliptic plane. The sun is then "allowed" to drift across the spacecraft line of sight for 24 hours before an attitude manoeuvre is performed to slew the spacecraft back to its start position. The instruments are designed to be compatible with this mode of operation.

A continuous pointing mode was considered whereby the spacecraft spin axis would always point at the sun centre due to the action of the thruster jets. However, this was rejected due to the higher number of disturbances which could occur with respect to the solar oscillation experiment and the continuous random errors which would disturb the solar imaging experiment.

3.3 Launch Constraints

The basic aim for DISCO has been to establish, as a result of the orbital analysis and optimisation, whether a year-round launch window exists, compatible with the Ariane dual-launch situation.

Firstly, the boost delta-V (out of G.T.O.) was found to lie always within a narrow range (738-742 m/s). The insertion delta -V into the Halo orbit varies considerably, however, and this is shown, plotted at 10 day intervals throughout the year, in Fig. 3.3(a). The 2 peaks which occur about a month before the Solstices are due to the larger out-of-plane components of the G.T.O. at these times which require correcting on entering the Halo orbit. Since the maximum delta-V of 165 m/s is compatible with the amount of fuel on board then a year-round launch can be achieved. However, some small restriction on a yearly launch window may be desirable for other reasons, in particular the effect of solar aspect angle (SAA) on the spacecraft power. The SAA restrictions can however still be met by suitably increasing the boost and injection delta-V values within the present spacecraft capabilities.

A likely constraint imposed by a partner spacecraft is that launch must take place within ± 2 hours of noon or midnight, meaning that the node of the G.T.O. must lie within ± 30° of the Earth-Sun line. Fortunately, this is always the case for the optimised trajectories derived for DISCO.

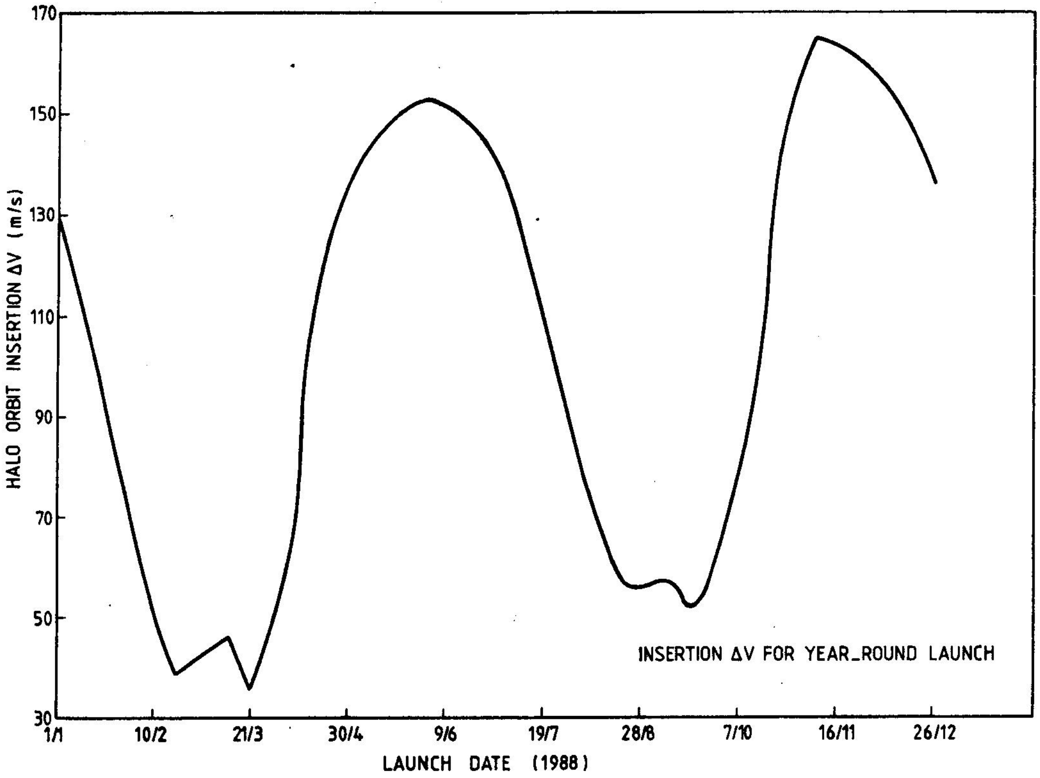


Fig. 3.3 a) Injection delta-V into Halo orbit as a function of time of year.

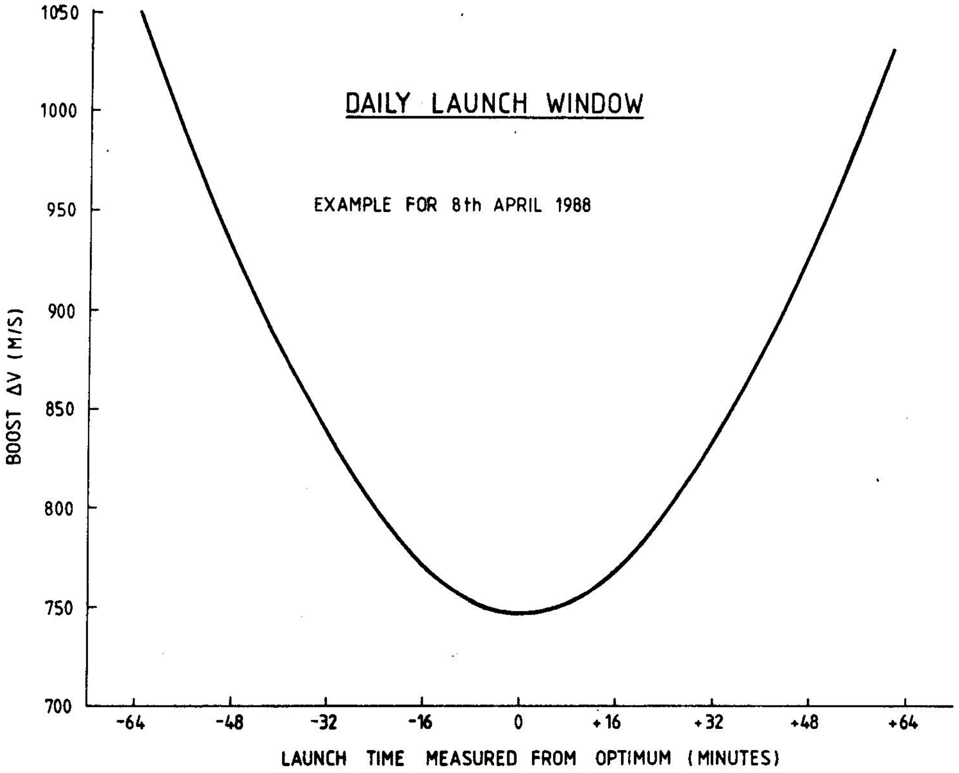


Fig. 3.3 b) Boost velocity as a function of launch window.

Finally, the launch authorities request a daily launch window of at least 45 minutes for operational flexibility reasons. This will cause an increase of boost delta-V compared with the optimum as illustrated in Fig. 3.3(b). A launch 45 minutes away from optimum will require a boost delta-V of 850 m/s, but this is still within the boost motor capability.

Additionally, mid-course manoeuvres are necessary to correct the injection errors of the boost motor. It is expected that three midcourse manoeuvres will be necessary, the first being by far the most critical. This has to be performed as soon as possible in the cruise phase in order to avoid large delta-V's since the delta-V increases rapidly with time. In fact the execution time of this first manoeuvre should be within 4 hrs. Table 3.1 shows the details of the three manoeuvres.

Manoeuvre	Time from injection	Delta-V m/s	Execution Errors, 3 sigma	Residual distance (km)
MCC1	12 to 20 hours	75-95	$\sigma_{\Delta v} = 4\%$ $\alpha = 1^\circ$	$= 10^6$
MCC2	30 days	7.5	$\sigma_{\Delta v} = 2\%$ $\alpha = 1^\circ$	16000
MCC3	70 days	0.5	$\sigma_{\Delta v} = 2\%$ $\alpha = 1^\circ$	250

Table 3.1 Mid-course manoeuvres

3.4 Station Keeping

Station keeping is required for several reasons: ellipticity of the Earth orbit and perturbation by the moon; errors in the orbit determination and the execution of the station keeping manoeuvres. First, it has been assumed that the orbit of the Earth is circular so that the Halo becomes periodic. In reality, however, the ellipticity of the Earth orbit is not negligible and the motion of the Moon and the Earth around their common barycentre perturb the Halo orbit. A computer simulation has shown that it is sufficient to constrain the periodic crossing of the y=o plane to be perpendicular. At each crossing of the y=o plane a small manoeuvre is performed, such that the next crossing after half a revolution later (about 3 months) is again perpendicular. Taking all orbital perturbations into account, but excluding orbit determination and manoeuvre execution errors, an average delta-V of about 1 m/s is required for each crossing. Figure 3.4 shows the orbit projection onto the xy (ecliptic) plane as an example.

After six years lifetime the last crossing of the xz-plane was not corrected and it is seen that after half a revolution the spacecraft has left the Halo orbit and moves towards the sun. This shows clearly the instability of the Halo orbits.

The major error sources are, however, the errors of orbit determination and the execution of the manoeuvres. The correction of these errors requires considerably more fuel.

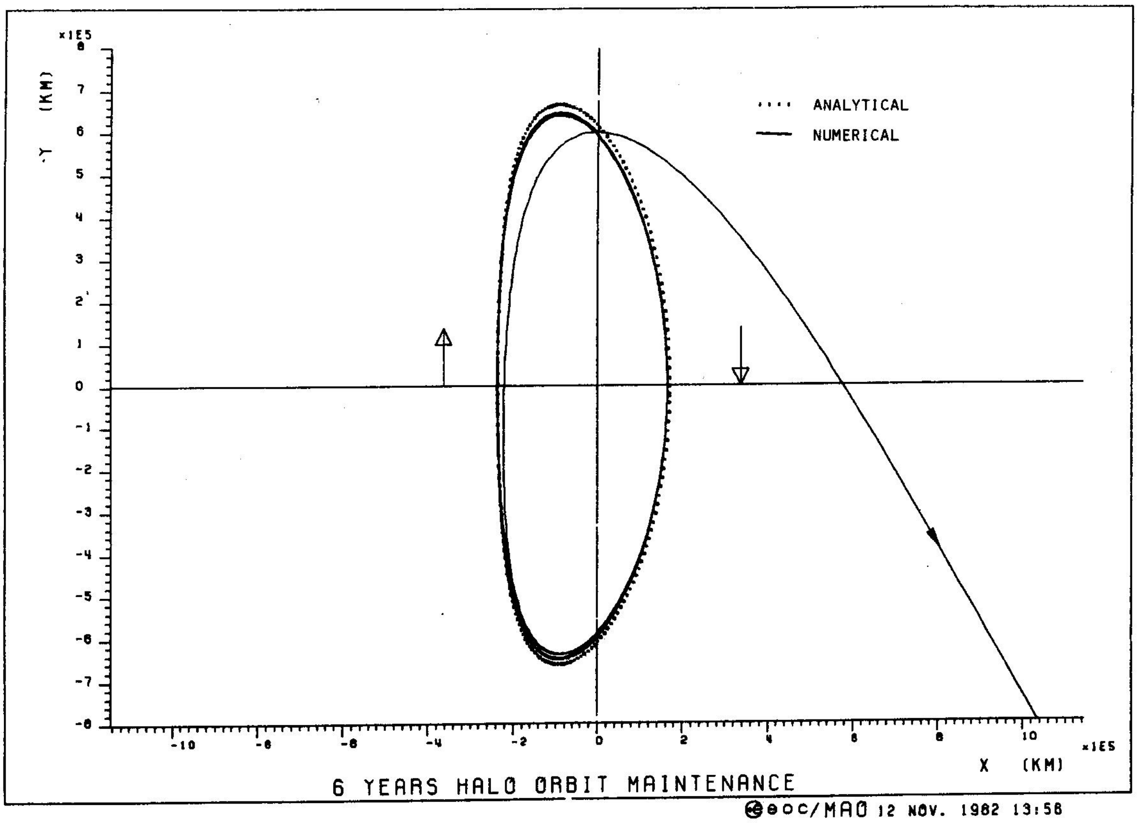


Fig. 3.4 Station keeping in Halo orbit

3.5 Overview of the Ground System

3.5.1 Control Centre and Ground Stations

The concept for controlling the DISCO mission is based on the use of a single control centre operating in conjunction with one of more ground stations, whose capability with the spacecraft's telemetry system ensures spacecraft control from launch until the end of the mission.

For the purpose of the Phase-A study, the following ground stations are assumed to be available to support DISCO:

Station	Location	Antenna Size
WEILHEIM	GERMANY	30 metres
CARNARVON	AUSTRALIA	15 metres
VILLAFRANCA	SPAIN	15 meters
ODENWALD	GERMANY	15 meters

During the immediate post launch phase up to cruise injection, the ground station above may be augmented by other stations of the ESA transfer orbit network (e.g. Kourou and Malindi).

During the cruise phase, which can last from 3 to 4 months the European stations will be used for TT&C operations. It is assumed that the spacecraft design will be such that it will not require more than 4 hours monitoring each day. During high activity periods such as the mid-course correction and L1 insertion a further station of the ESA network may be called up. Tracking data would be acquired daily during the four hour pass. For the first few days of the cruise phase, tracking data would be acquired at higher intervals and from more than one station.

TT&C for the Mission Operations phase will be provided by the Villafranca or Odenwald ground stations with data acquisition covering an average for the two-year mission of 8 hours each day. Range and doppler data will be available from one of these stations as well as from Canarvon in Australia.

The Ground network for DISCO is shown schematically in Figure 3.5.

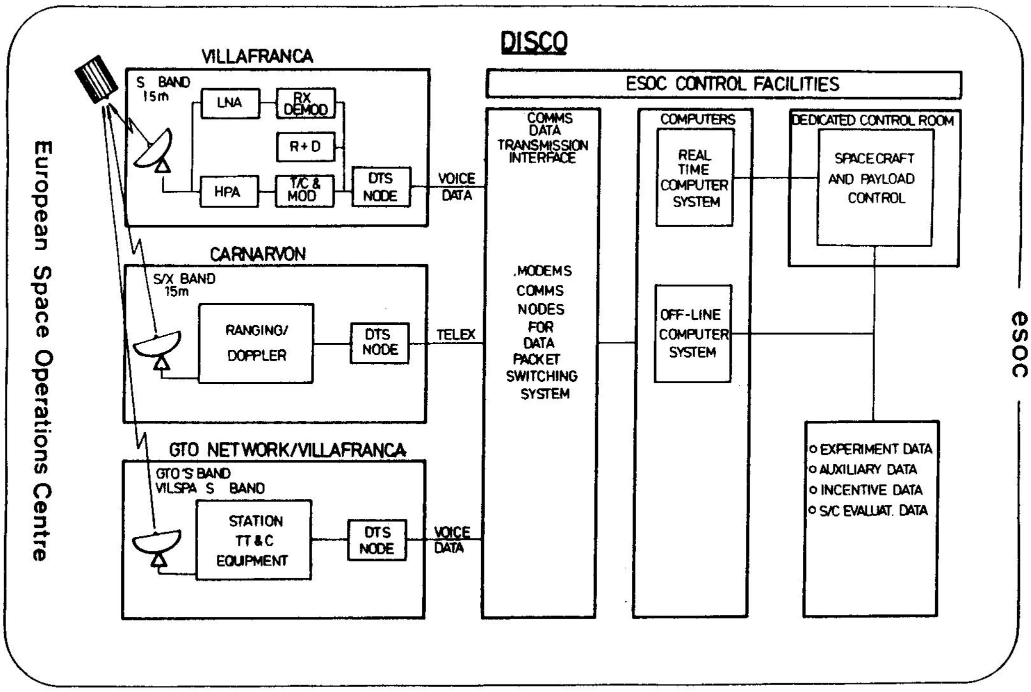


Fig. 3.5 Ground System

The DISCO data processing for Spacecraft Monitoring and Control will be undertaken on the Multi-Satellite Support System (MSSS). Special software will be developed for the flight dynamics and payload data processing while the MSSS will be augmented to cover specific monitoring and control tasks for DISCO.

Payload data will be processed for the scientific institutes and auxiliary data (e.g. solar activity data, orbit emphemeris, etc.) will be either merged with it or provided on separate magnetic tapes.

3.5.2 Operations

(i) Launch and Early Orbit Phase

The spacecraft will be launched from the CSG launch complex at Kourou and injected into an elliptical transfer orbit. The ground operations supporting these activities will cover a period starting from first acquisition of the telemetry signal after launch vehicle seperation to the completion of the spacecraft injection into cruise trajectory and are expected to cover the following activities:

- spacecraft data acquisition, subsystem status and activation of on-board subsytems;
- determination of intial transfer orbit parameters;
- analysis of spacecraft subsystems performance;
- determination of attitude achieved;
- refined orbit determination and optimisation of boost motor (BM) firing for cruise trajectory injection;
- attitude manoeuvre to optimal BM firing direction;
- BM firing operations and injection into cruise phase orbit.

(ii) Cruise Phase

These activities are summarised in figure 3.6

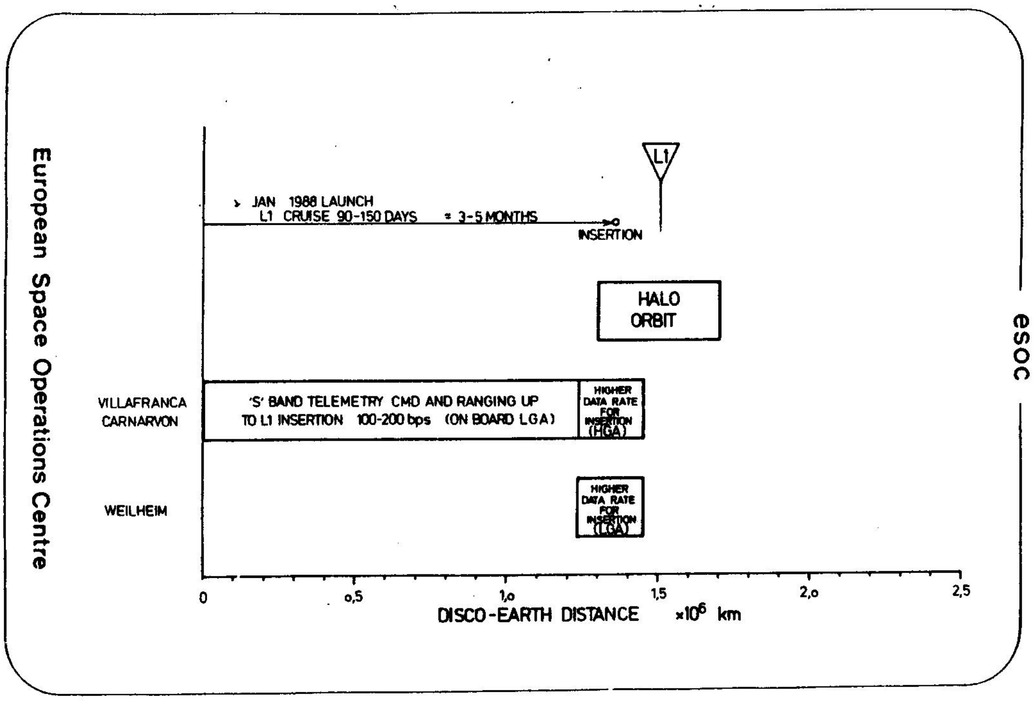

European Space Operations Centre
esoc
JAN 1988 LAUNCH
L1 CRUISE 90-150 DAYS ≈ 3-5 MONTHS
INSERTION
L1
HALO ORBIT
VILLAFRANCA
CARNARVON
'S' BAND TELEMETRY CMD AND RANGING UP TO L1 INSERTION 100-200 bps (ON BOARD LGA)
HIGHER DATA RATE FOR INSERTION (HGA)
WEILHEIM
HIGHER DATA RATE FOR INSERTION (LGA)
0
0,5
1,0
1,5
2,0
2,5
DISCO-EARTH DISTANCE ×10^6 km

Fig. 3.6 'S'Band Cruise Operations

During the three to four months the spacecraft will take to reach the libration point the spacecraft commissioning activities will be undertaken and controlled. In addition, some of the experiments may be checked out and activated to allow a certain level of cruise science to be undertaken. A mid-course correction manoeuvre will be carried out to accurately set the spacecraft's trajectory for insertion into orbit around L1.

For the cruise the spacecraft will mainly be monitored and controlled from the DISCO Dedicated Control Room (DCR) at ESOC. Mission critical operations such as mid-course correction and Libration insertion manoeuvres will, however, be controlled from the Mission Control Room at ESOC.

(iii) Libration Orbit Insertion

During this phase the spacecraft will be injected into orbit around L1. The operation will be initiated from the MCR at ESOC and will require the use of a 30 m dish if the on-board L.G.A. is used for this phase.

(iv) Mission Operations Phase

The orbital operations of DISCO will start when all the payload subsystems have been checked out subsequent to their initial activation. This will be followed by the mission proper. The period of the Halo Orbit and the time at which the spacecraft is inserted into it will be optimised for maximum ground station coverage, with the aim of giving at least 8 hours contact each day at the single ground station chosen.

4. SPACECRAFT CONFIGURATION AND PERFORMANCE

4.1 Requirements and Constraints

The requirements arising from the scientific payload are explained in section 2.0. In order to recap they can be listed briefly as:

- continuous and uninterrupted viewing of the sun for a minimum of 1 year
- high degree of short term spacecraft velocity stability in the sun direction
- minimize spacecraft absolute velocity in the sun direction
- high pointing accuracy and stability of spacecraft spin axis
- high accuracy measurement of spin phase angle
- absolute minimum of chemical contamination
- high degree of electromagnetic cleanliness.

The constraints on the mission arise from the choice of launcher and the approach to minimise costs. The launcher constraints dictate that DISCO be compatible with the volume and launch mass capability available in the lower SYLDA of the ARIANE launcher. In addition, DISCO must be equipped with a perigee boost motor capable of putting the spacecraft into transfer orbit to L1. Spacecraft stability must also be retained for all mission phases. This is no problem in the operational phase, but in G.T.O. with boost motor attached and booms stowed the problem is more acute. Stability has been achieved here by siting the equipment platform as low as possible on the central cylinder.

It could be envisaged that there should be no shortage of power for DISCO since it faces the sun throughout its operating life. However, conditions in G.T.O. dictate that a substantial amount of energy has to be carried in batteries.

Attitude control during transfer and cruise orbits can be achieved by means of sun and earth sensors whereas telecommunications during these phases are performed by low gain antennae. In Halo orbit telecommunications are via an on-board high gain antenna. The beam-width of this antenna dictates the maximum Halo orbit amplitude.

On orbit the relatively high amount of continuous data required leads to two problems: - (i) Real time data transmission at the extreme Halo orbit amplitudes reduces the nominal transmitted data rate from about 3 Kb/s to about 2 Kb/s (edge losses in antenna gain); (ii) Out of contact period with single ground station is about 16 hours leading to a large on-board data store.

Pointing accuracy and stability requirements during operation lead to the use of a high accuracy fine sun sensor plus a star mapper. Spacecraft dynamics problems (coupling with long booms during thrusting) lead to requirements for careful placing of individual thrusters together with constraints regarding their force levels and on-times. Additionally, a thruster pulsing strategy is needed and particularly severe constraints arise during orbit correction manoeuvres. In order to neutralise the "line of sight" velocity disturbance arising from nutation effects the HRS experiment viewing aperture is placed on the spacecraft spin axis.

The desire to measure changes in spacecraft line of sight velocity to a very accurate level (1 mm/s) leads to the use of accurate Doppler tracking techniques. Since this level of accuracy cannot be achieved in this way accelerometers on-board will supply data on accelerations in spacecraft body axes to the experimenters.

4.2 Configuration

Figure 4.1, below, shows the elements of the DISCO configuration, whereas the detailed layout is shown in figure 4.2(a) and (b) overleaf.

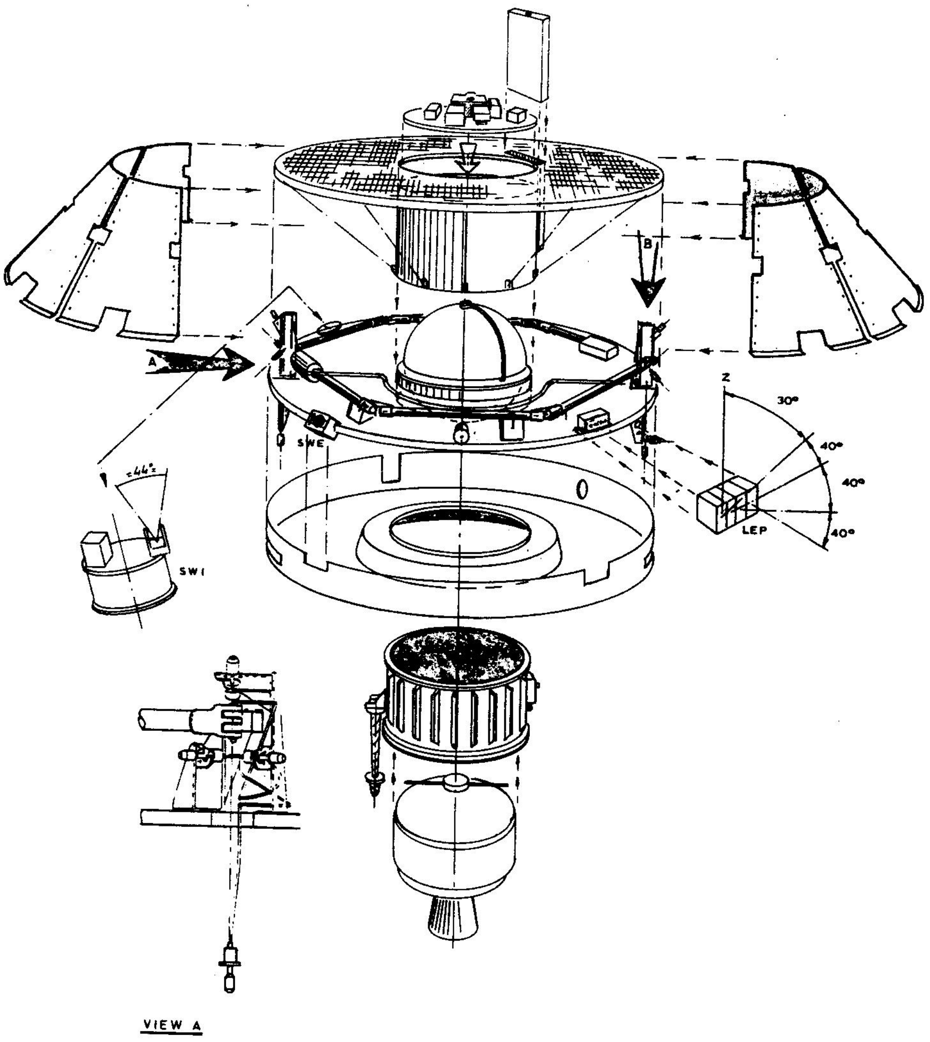


Fig. 4.1 DISCO Configuration

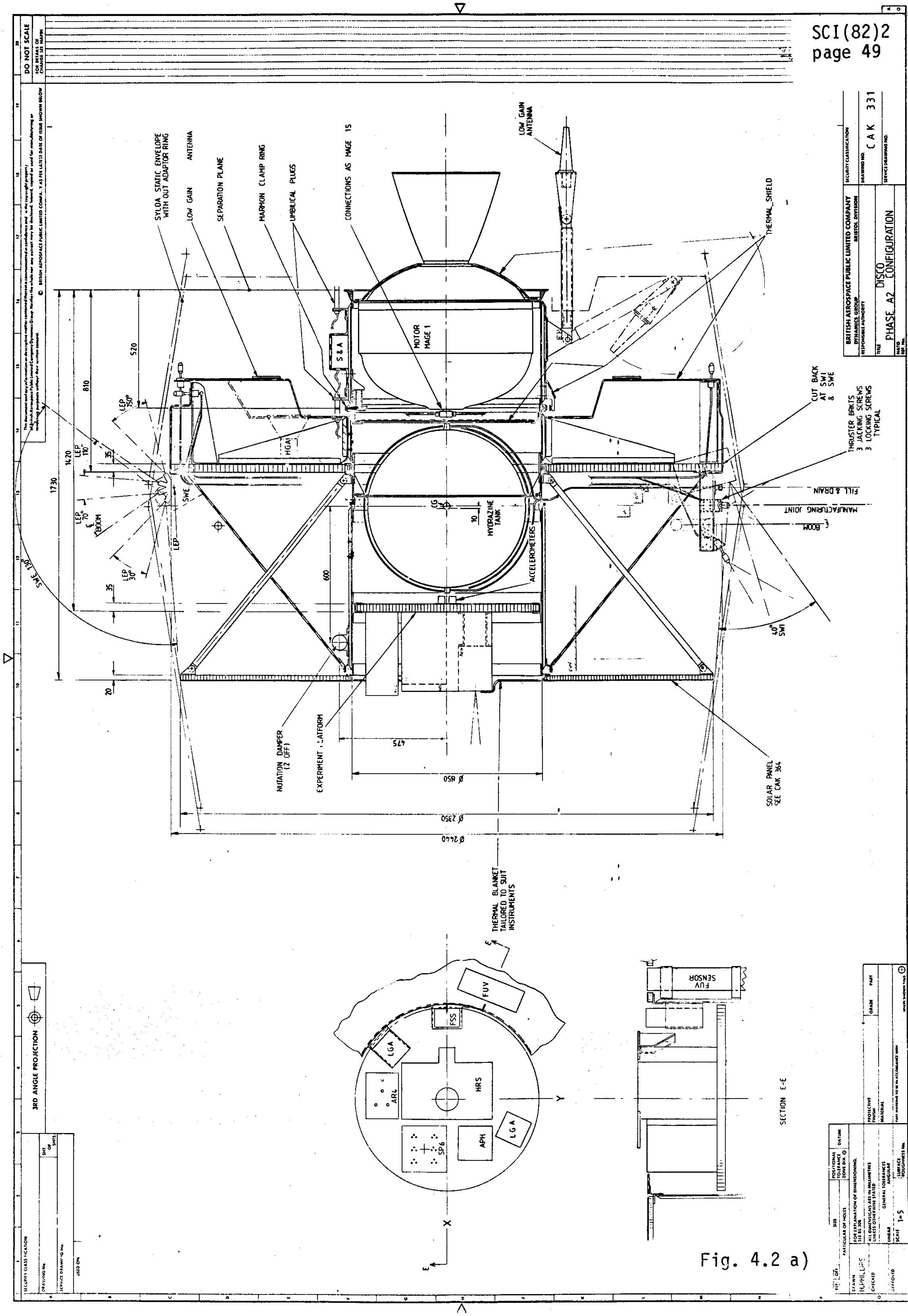

DO NOT SCALE
3RD ANGLE PROJECTION
SYLDA STATIC ENVELOPE WITH OUT ADAPTOR RING
LOW GAIN ANTENNA
SEPARATION PLANE
MARMON CLAMP RING
UMBILICAL PLUGS
CONNECTIONS AS MAGE 1S
LOW GAIN ANTENNA
THERMAL SHIELD
MOTOR MAGE 1
S & A
HGA
LEP 150°
LEP 110°
LEP 70°
LEP 30°
BOOM
SWE
SWE 130°
LEP
CG
10
HYDRAZINE TANK
ACCELEROMETERS
CUT BACK AT SW1 & SWE
THRUSTER BRKTS 3 JACKING SCREWS 3 LOCKING SCREWS TYPICAL
FILL & DRAIN
MANUFACTURING JOINT
BOOM
40° SW1
FUV
NUTATION DAMPER (2 OFF)
EXPERIMENT PLATFORM
SOLAR PANEL SEE CAK 364
1730
1420
810
520
35
35
600
20
475
Ø 850
Ø 2350
Ø 2440
THERMAL BLANKET TAILORED TO SUIT INSTRUMENTS
E
FUV
FSS
LGA
AR4
HRS
SP6
APH
LGA
Y
X
E
FUV SENSOR
SECTION E-E
BRITISH AEROSPACE PUBLIC LIMITED COMPANY
DYNAMICS GROUP
BRISTOL DIVISION
DRAWING NO. CAK 331
TITLE PHASE A2 DISCO CONFIGURATION
DRAWN H.PHILLIPS
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Fig. 4.2 a)
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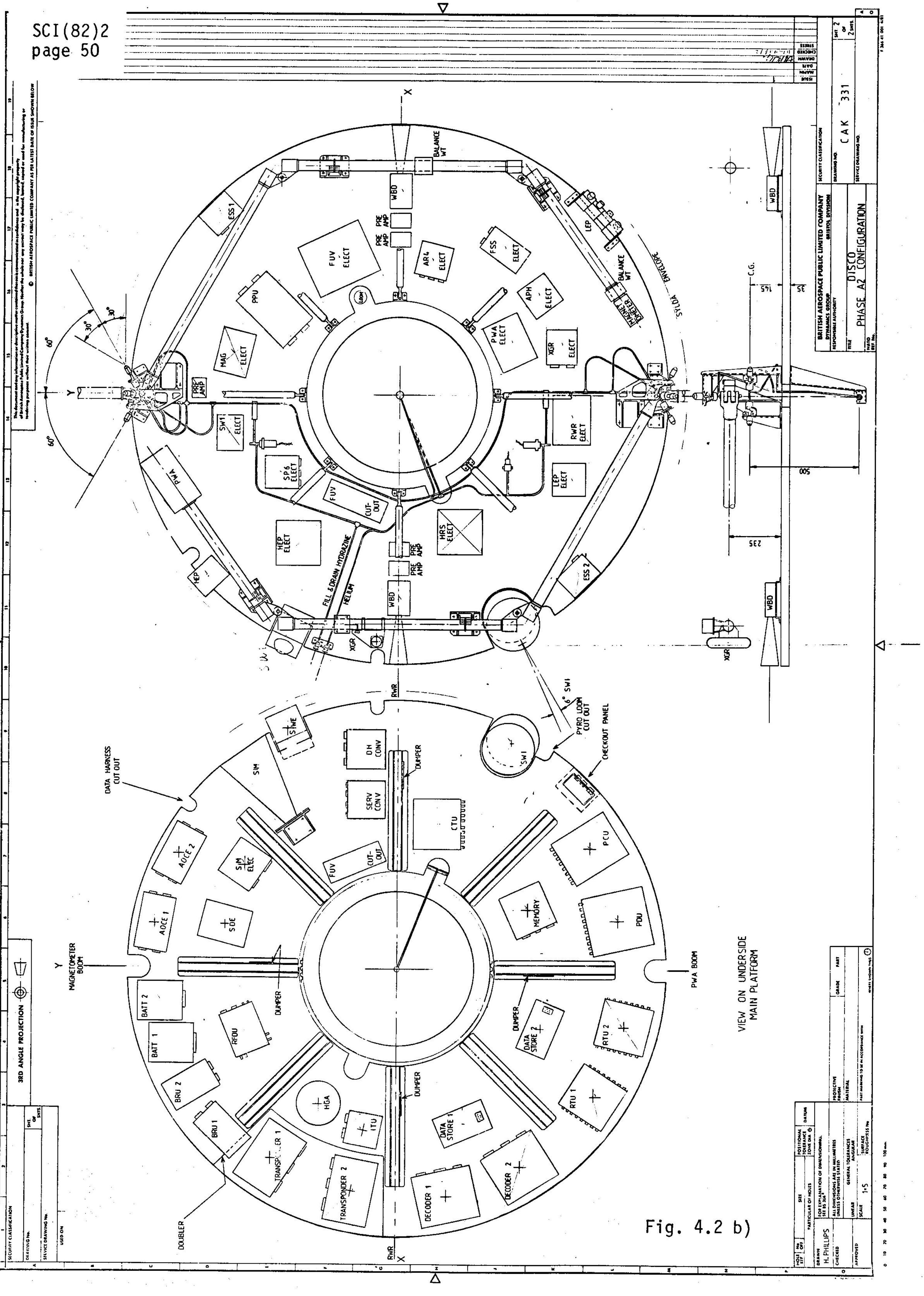

BRITISH AEROSPACE PUBLIC LIMITED COMPANY
DYNAMICS GROUP
BRISTOL DIVISION
DISCO
PHASE A2 CONFIGURATION
CAK 331
SHT. 2 OF 2 SHTS.
H. PHILLIPS
3RD ANGLE PROJECTION
SCALE 1:5
VIEW ON UNDERSIDE MAIN PLATFORM
SYLDA ENVELOPE
BALANCE WT
WBD
PRE AMP
FUV ELECT
AR4 ELECT
FSS ELECT
APH ELECT
LEP
ESS 1
ESS 2
PPU
MAG ELECT
PWA ELECT
XGR ELECT
SW1 ELECT
RWR ELECT
SP6 ELECT
LEP ELECT
FUV CUT-OUT
HRS ELECT
HEP ELECT
HEP
PWA
FILL & DRAIN HYDRAZINE
HELIUM
XGR
C.G.
145
35
500
235
60°
30°
X
Y
RWR
6° SW1
PYRO LOOM CUT OUT
CHECKOUT PANEL
DATA HARNESS CUT OUT
SIM
SIM ELEC
SW1
DH CONV
SERV CONV
CTU
DUMPER
PCU
MEMORY
PDU
AOCE 2
AOCE 1
SDE
MAGNETOMETER BOOM
PWA BOOM
BATT 2
BATT 1
RFDU
BRU 2
BRU 1
HGA
ITU
DATA STORE 1
DATA STORE 2
RTU 1
RTU 2
DECODER 1
DECODER 2
TRANSPONDER 1
TRANSPONDER 2
DOUBLER

Fig. 4.2 b)

Of the various options considered, the choice of a simple cylindrical spinning spacecraft with fixed annular array is a good compromise with respect to meeting payload requirements at a reasonable cost. Initial trade offs, for example, indicated that a dual spin spacecraft would also satisfy the experimenter requirements, but at much higher cost. Having chosen the basic configuration further trade-offs were performed on the major subsystems.

Because of the unfavourable spacecraft orientation in G.T.O. consideration was given to the use of folding solar panels. This was felt to be an unnecessary complication, however, introducing additional machanisms and a further source of pointing instability for a singular condition which can be covered by the use of batteries.

Distributed hydrazine tanks as originally proposed were felt to have a number of problems which can be summarised as follows:

- introduction of thermal problems (localised "hot-spots") with respect to the solar array
- taking up of platform space needed for experiments and subsystems
- uncertainty of the effects of fuel slosh on pointing accuracy
- possible destabilising effect of uneven fuel depletion in tanks.

For these reasons a single large central tank was chosen which minimises these problems and in addition leads to a simpler subsystem (less piping and fewer valves). Furthermore, experience of such a single tank solution has been obtained on the ISPM programme and simplifies the integration and test aspects.

The sun pointing experiments are referenced to the sun sensor mounted on the upper central cylinder. Most sun pointing experiments are mounted on a lowered platform attached inside this cylinder. The FUV, however, because of its length is attached to the outside of this cyclinder. The remaining (heliospheric) experiments are mounted mainly on the upper surface of the lower platform, with spacecraft subsystem units being mounted on its lower surface. The HRS viewing aperture is arranged to be on the spacecraft spin axis in order to neutralise sun direction velocity changes due to nutation effects.

In addition two sets of booms are carried - two short radial booms (approx. 2 - 3m long) and two long wire booms (each 35m long).

Thrusters are mounted on the lower platform. The upper axial thrusters are canted to minimise plume impingement on the solar array. A lower radial thruster is used since a shorter moment arm is thereby achieved which reduces the dynamic coupling with the long booms.

The upper surface of the lower platform equipment is covered by a conical thermal blanket which also serves to control the temperature of the back of the solar array.

4.3 System Performance

The system performance of DISCO is summarised in table 4.1 and the functional block diagram shown below in Figure 4.3. The aspects which need highlighting are pointing performance and velocity stability.

a) Pointing Performance

Several sources of pointing error can occur in a spinning spacecraft. The major ones are as follows:

. Principal (spin) Axis Tilt

The spin axis of a spacecraft is measured on the ground on a spin balance machine. Experiments and sun sensor are aligned and the alignment of these items with respect to the spin axis is then known (to within a high degree of precision). After reaching its operational orbit, however, the spacecraft spin axis has tilted due to various effects including structural and thermal deformations of unknown magnitude, and the effects of the booms. The effect of the tilt is to impart a coning motion on the experiment line of sight (instead of a pure rotation about a point). Since this is a fixed error its magnitude can be determined (e.g. by an imaging instrument) and corrected, for example by altering the experiment line of sight direction internally by using a moving mirror. The magnitude of principal axis tilt on DISCO is limited to 6 arc mins.

. Pointing Error

This is a random error arising from the lack of exact knowledge of the position of the spin axis with respect to the on-board sensors and the errors in thruster performance and alignment which prevent the spacecraft from reaching the exact position to which it is commanded. Pointing errors on DISCO are limited to a maximum of 4 arcmins with a goal of 1 arcmin.

. Dynamic Errors

Dynamic errors manifest themselves as a "wobble" or "nutation" of the spin axis as a result of disturbances (especially thruster firing) introduced into the spacecraft. The two dynamic errors of importance for DISCO are (i) the Nutation (N) mode, which involves coning motion of the centre body and which is damped out relatively quickly by the use of nutation dampers and (ii) the Meridian antisymmetric (MA) mode. This latter mode is of higher frequency than (i) and involves coupling of the centre body with an antisynumetric boom motion. The N and MA modes are coupled in practice but can be analysed seperately.

These dynamic effects can have considerable impact on pointing performance and stability and require significant analysis and careful spacecraft design in order to minimise their effects. Computer simulations have been performed to evaluate the effects of thruster firing. The amplitude of the dynamic mode depends on the

Table 4.1 DISCO System Performance

Characteristics	Requirement	Performance
Scientific Objectives	Global Sun Observatory combined with heliospheric plasma/particle experiments to support ISPM	Objectives are met. DISCO carries a payload of instruments designed to perform all required measurements
Payload Mass	95 kg	95 kg
Payload Power	average 96 W pk 126 W (for 4hrs during FUV ops)	average 96 W pk 126 W (for 4hrs during FUV ops)
DISCO launch mass	904 kg	938 kg (Ariane 2 nominal dual launch capability taking into account SYLDA mass
DISCO all-up mass on-orbit	-	587 kg (B.O.L.)
Spin Rate	"low"	± 5 rpm
Lifetime in orbit	2 years	minimum 2 years
Total power (end of life)	payload power of 126 W + subsystem power (max) 120 W	246 W (at end of 2 years)
Telemetry	Uninterrupted data stream of 40 b/for seismology + min. continuous data rate of 560 b/s for heliospheric science gives total requirements of 2 kb/s real time + 30 Mb store.	average 3 kb/s real time + 30-35 Mb store.
Special Payload Requirements		
- Solar Seismology	- velocity stability in sun direction always 1 mm/s	1 mm/s according to simulation based on chosen thruster layout/operation for daily slew. 40-70 mm/s for orbit correction approx. once every 3 months.
	- measurement of sun direction Delta-V = 1 mm/s	Doppler ranging gives approx. 3-10 mm/s average. Dual axis accelerometer data can additionally be supplied by expts.
	- continuous sun pointing	Halo orbit at L1 + daily att. control
- Solar imaging	- spin axis relative pointing accuracy 10"/min	Can be achieved by using correct strategy to minimise spacecraft - long boom dynamic coupling
	- principal spin axis tilt 6 arc mins	5 arc mins according to error budget analysis.
	- absolute pointing error of principal spin axis 4 arc mins during imaging period	analysis indicates that higher pointing accuracy (1 arcmin) can be achieved.
- Heliospheric Science	- always in solar wind and in ecliptic plane	satisfied by L1 orbit

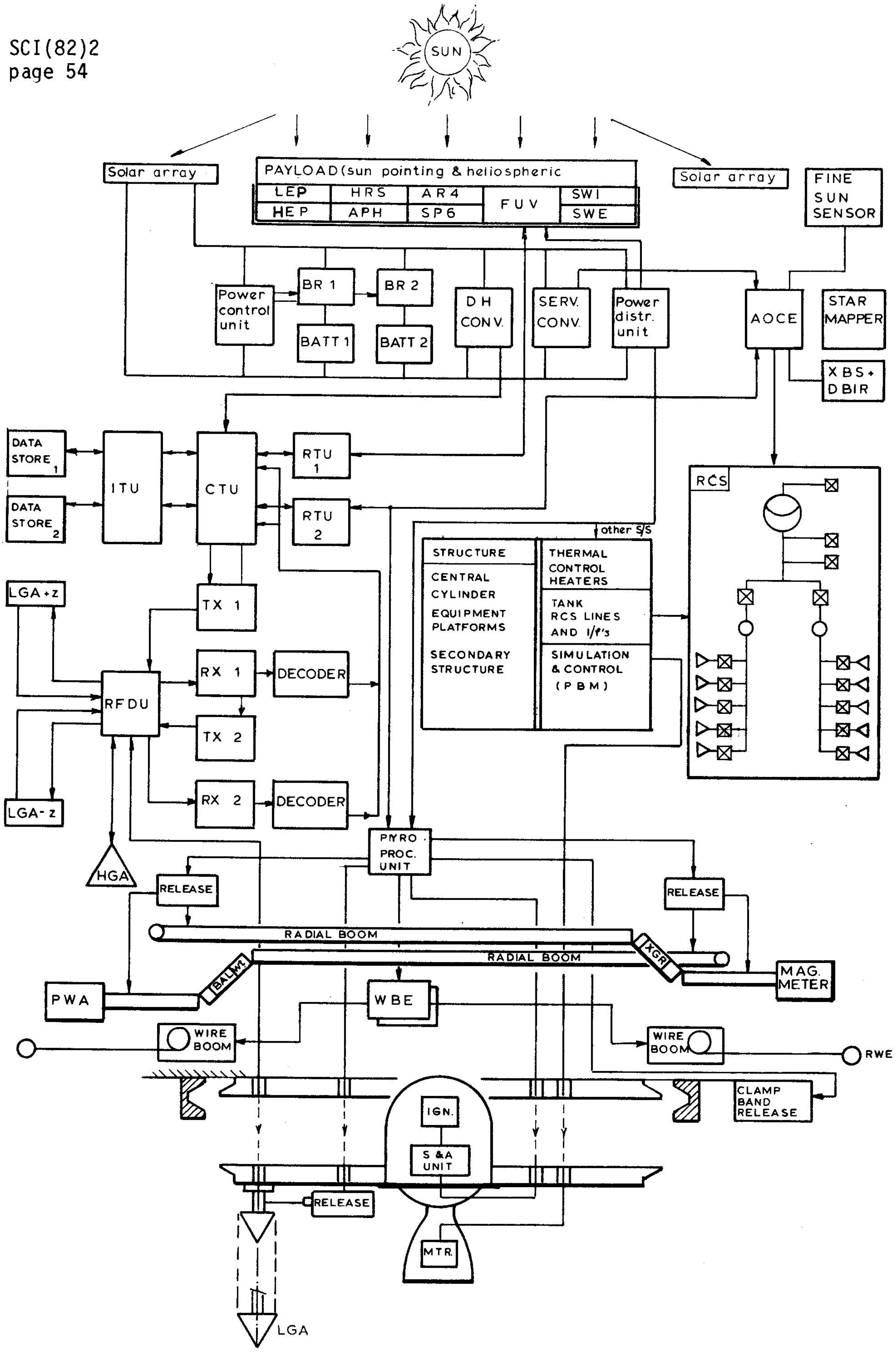


Fig.4.3 DISCO SYSTEM FUNCTIONAL BLOCK DIAGRAM

thruster firing cycle. For the N mode it is found that firing at high level duty cycle (once per spin) gives the smallest amplitude, whereas for the MA mode a low firing duty (e.g. once per four spins) gives the lowest effect. Once per four spins is, in fact, about the lowest realistic limit.

Again there is a "beat" effect with the disturbances such that if the correct number of thrust pulses is chosen the end of the manoeuvre is at a point of minimum disturbance. This has two disadvantages, however, vis: -

(i) the fundamental boom frequency must be known to a high accuracy and measured in orbit (this may be possible via the CONSCAN system)
(ii) the pulse duration must be varied in order to always achieve a fixed (1°) slew.

Illustrative simulation results are given in Figs. 4.4 (a),(b), and (c) showing spin axis movements for the daily attitude correction manoeuvre for various conditions, using two axial thrusters.

Now the relevant requirement for dynamic stability is that the spin axis pointing accuracy during solar imaging must be = 10 arc secs. over any 1 minute period. Since the N mode damps out relatively quickly then only the MA mode is expected to remain at this time. With axial thrusters placed approx. 1m from the spin axis this requirement is not achieved. Moving them near the spin axis would reduce the disturbance but it is not a practical solution. A single radial thruster has been chosen since this can be placed nearer the c.g. and additionally the thrust time is reduced from 100 ms to 50 ms. The residual dynamic disturbances are given in the table below, based on the assumption that nutation and boom root dampers are present. Since only the MA mode is present during imaging and its period is approximately 9 minutes then the tolerable disturbing amplitude (θ_{ma}) is given by

$$2\pi\theta_{ma}/\ 9\text{mins.} \leq 10 \text{ arcsec/min}$$

$$\text{ie. } \theta_{ma} \leq 15 \text{ arcsec.}$$

Thruster Mode	Dynamic Disturbance Amplitude		
	Initial	After 7,6 hrs.	After 10 hrs.
2 axial m = 3	21 arc mins	89 arc secs	48 arc secs
2 axial m = 4	18 arc mins	68 arc secs	37 arc secs
1 radial m = 3	5 arc mins	20 arc secs	11 arc secs
1 radial m = 4	4 arc mins	15 arc secs	8 arc secs

These figures indicate that such as requirement could be met. Further reductions could be achieved by shortening the length of the wire booms.

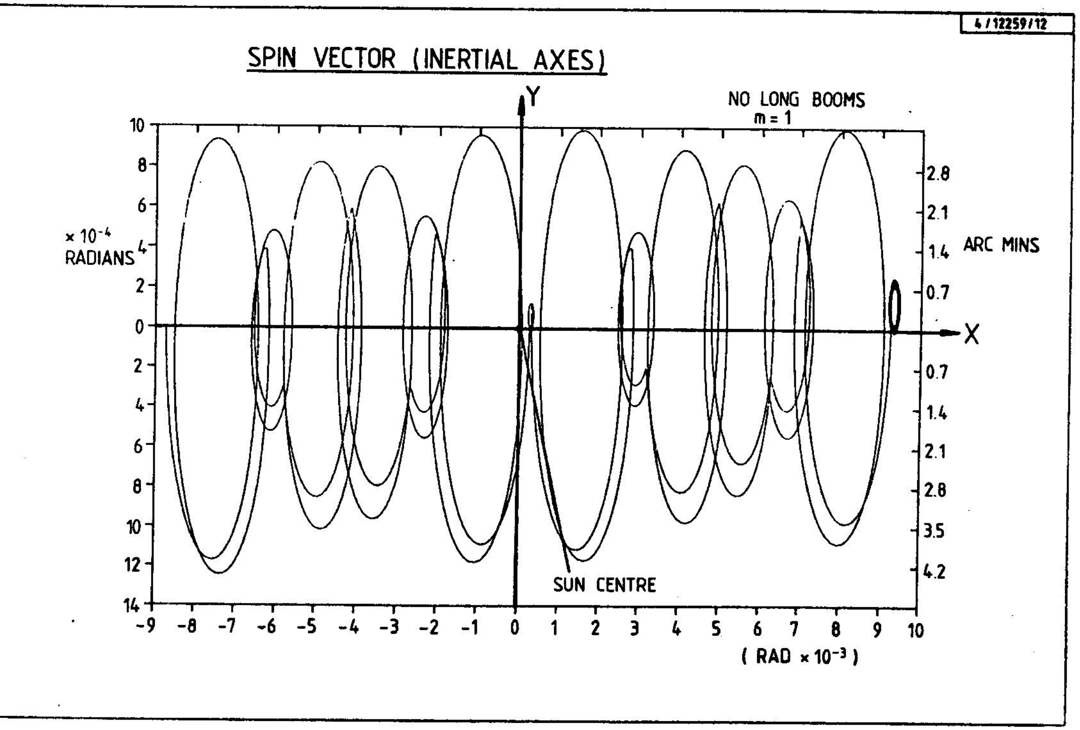
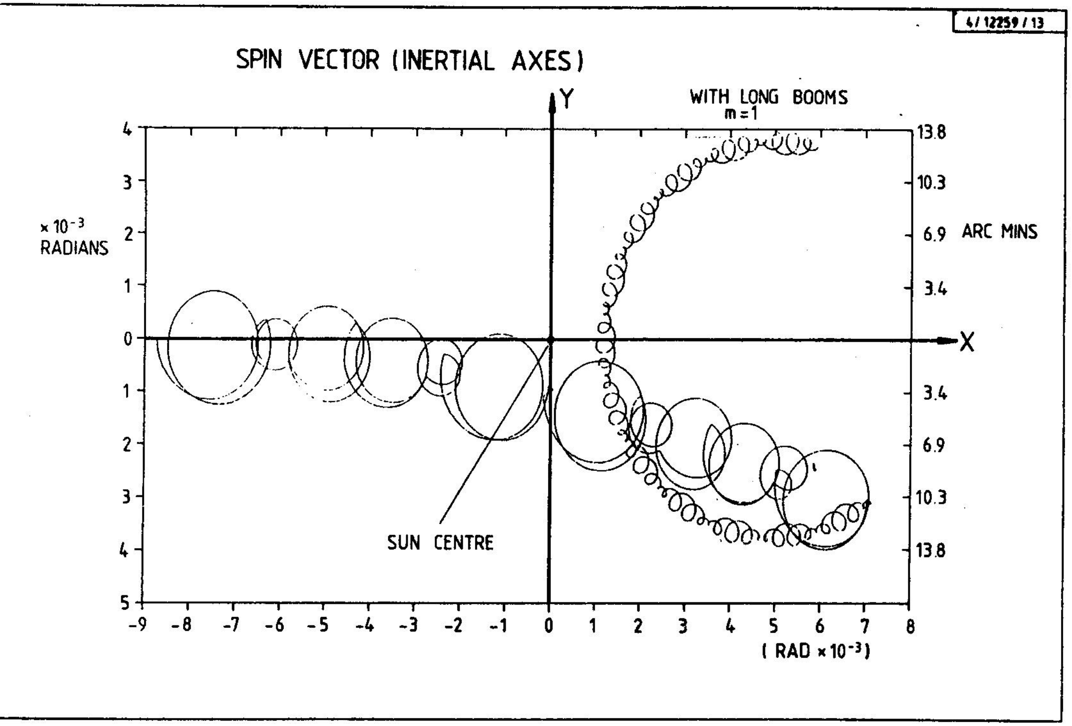
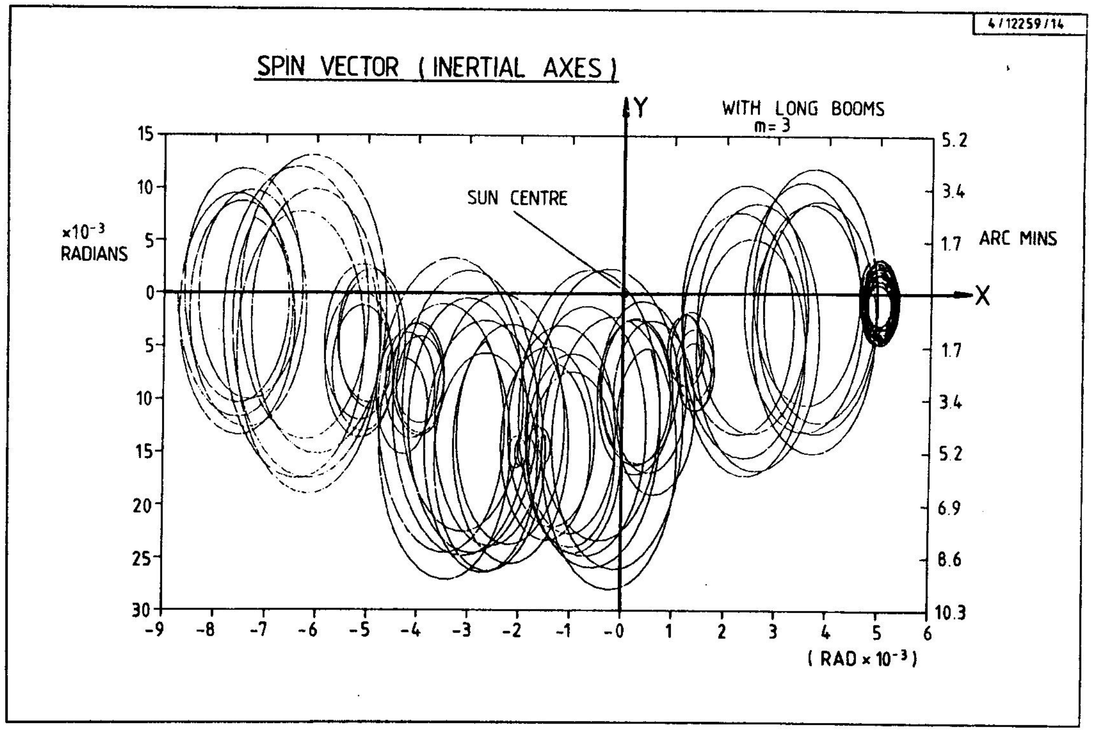


Fig. 4.4 Spin Vector History During Daily Attitude Correction.

a) No booms. m = 1
b) With long booms. m = 1
c) With long booms. m = 3





b) Velocity Stability

The simulations presently show that the short term velocity stability of 1 mm/s in the sun direction for the spacecraft can be met for the daily manoeuvre case. Using a single radial thruster the value does not exceed 0.2 mm/s. The investigation of station keeping manoeuvres shows, however, that this value can be exceeded if relatively infrequent manoeuvres (once every 3 months) are carried out. For example for a typical station keeping manoeuvre of 5 m/s delta-V a line of sight velocity of 30 mm/s is imparted to the spacecraft.

However, it seems that the requirement can be relaxed if the spacecraft sun direction velocity change can be measured to an accuracy of 1 mm/s. A potential method of achieving this is by Doppler ranging. An arc of the orbit would have to be measured before and after the manoeuvre took place and the two averaged results subtracted. From Fig. 4.5 it is seen that at least 25 days of data using 2 ground stations is required before

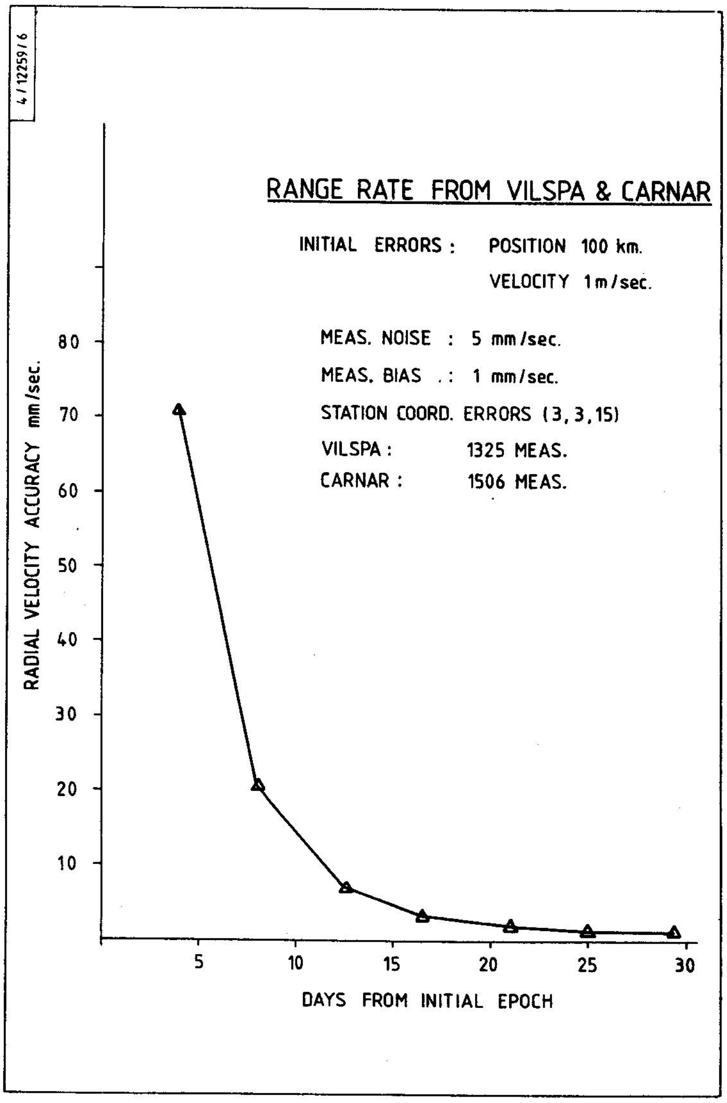


Fig. 4.5 Doppler Ranging Accuracy with Time

the required accuracy is approached. In fact the best results expected from this method would lie in the range 3 mm/s to 10 mm/s depending on the spacecraft position in Halo orbit. This method gives only the averaged results and says nothing about instantaneous velocities, which would have to be predicted analytically.

Another possibility considered was to use a single accelerometer placed on the spacecraft spin axis. In this case there are several problems,

- parasitic accelerations due to principal axis tilt
- cross axis sensitivity of the accelerometer
- no response to pure radial thrusting in body axes, even though a sunward movement of the spacecraft could occur.

Consideration of these error sources indicates that the required measurement accuracy of instantaneous spacecraft velocity change is unlikely to be achieved by an on-board accelerometer.

In conclusion it can be stated that the velocity stability for daily correction can be met, whereas for the orbit keeping manoeuvres further investigation of the following areas is needed:

1. Interpretation of tracking data. For example the above calculations assume that bias errors are present. If these bias errors can be removed - for example if they are negligible or only slowly varying over the critical tracking period - then the curve of figure 4.5 both converges more rapidly and achieves a higher accuracy (better than 1 mm/s).

2. More frequent station keeping manoeuvres. The present station keeping manoeuvre philosophy (once every 3 months) is based on the desire to disturb the spacecraft at as infrequent intervals as possible. This is seen, however, to produce a large disturbance. More frequent manoeuvres with lower disturbances (ideally below 1 mm(s) can, therefore, be investigated.

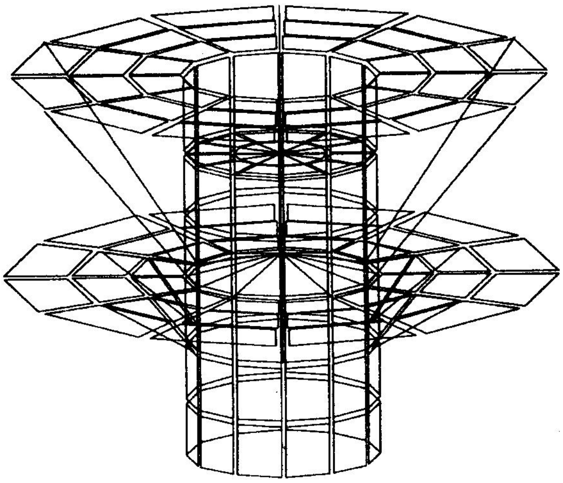
3. Supplementary experiment data. An investigation can be undertaken to see whether one or more accelerometers could be placed inside the experiment package and the data combined with the experiment solar pointing accuracy data in an attempt to provide more accurate estimates of instantaneous velocity changes. Investigation of experiment analysis methods could also be used to predict in more detail the velocity change effects. For example, concerning the expected delta-V amplitude levels, a Fourier analysis of the 3-monthly manoeuvres indicates a negligible effect in the frequency range of interest.

4. Prediction of spacecraft motion. From the known spacecraft characteristics and knowledge of the thruster performances, accurate predictions of the spacecraft motion can be made. These predictions could possibly be checked with in-orbit calibrations to give high confidence in the results.

5. SUBSYSTEM DESIGN

5.1 Structure/Thermal

The load carrying part of the structure consists essentially of a central cylinder and lower platform connected to it via struts. Structural analysis has been performed using a quarter symmetric finite element model and checked using the full model shown alongside. The central cylinder is in two parts for ease of integration. The annular array and solar viewing instruments are attached to the upper part, with the lower platform, hydrazine tank and the ejectable boost motor attached to the lower part. The lowest mode found in the quarter model analysis is a platform mode and the frequencies for the first ten modes are shown in Table 5.1.

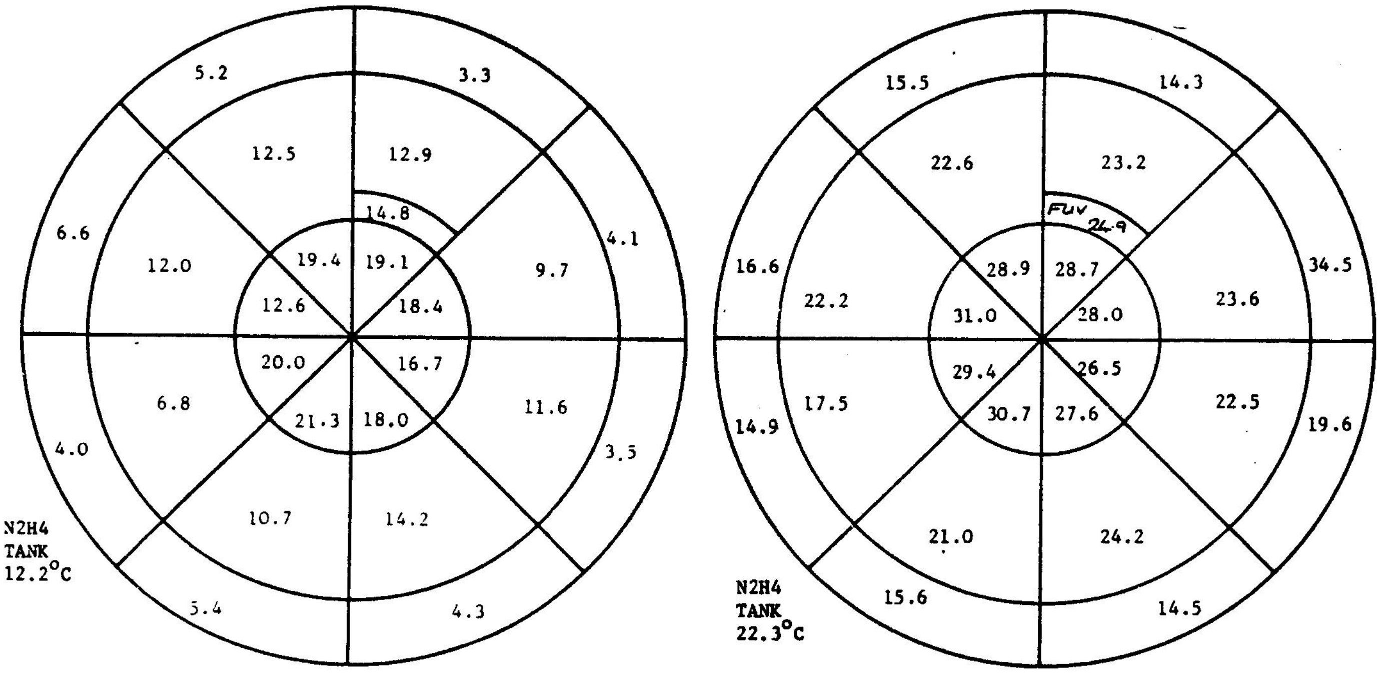


Symmetric - Symmetric Normal Modes		Symmetric - Antisymmetric Normal Modes	
Mode	Frequency (Hz)	Mode	Frequency (Hz)
1	39.85	1	41.71
2	42.97	2	43.77
3	75.27	3	78.06
4	84.15	4	79.51
5	88.32	5	87.56
6	107.13	6	93.13
7	118.73	7	119.29
8	130.90	8	131.32
9	133.35	9	132.80
10	140.75	10	137.24

Table 5.1 Frequencies of First 10 modes (Quarter Model)

A "cone" of thermal material is mounted on the top part of the lower platform, which will serve the dual purpose of thermally isolating the equipment beneath the cone and reflecting via the upper surface the heat radiated from the lower surface of the solar array. Array temperatures will be highest on the innermost part of the annulus. However, this region does not have solar cells since sufficient power can be obtained from the remaining area. A radiator skirt is mounted on the lower periphery of the lower platform. The panels have a selected combination of OSR's and black paint which according to the thermal analysis keep the equipment within specified temperature limits on station. In G.T.O. temperatures will vary depending on sun orientation and some heaters will be needed. Analysis of the array output during these periods has shown thatsufficient power is available for the required heaters.

Analysis has shown that the sensors and electronics always remain in the range 0°C to 35°C. Some calculated temperatures for the platforms on orbit are shown in figure 5.1.



HOT CASE
FUV OFF
OUT OF CONTACT
NO HEATERS

HOT CASE
IN-CONTACT
1450 W/m^2

Figure 5.1 Calculated Platform Temperature Extremes

5.2 Solar Array

Since DISCO has its spin axis pointing toward the sun throughout its operational life, a fixed annular solar array has been chosen. Trade-offs against folding arrays have shown that this type of array can meet the power requirements at a lower cost and with less impact on reliability, configurational complexity, pointing performance and experiment accommodation. This type of array is used also on the SME spacecraft.

For DISCO the available array area is 3,74 m^2. Due to limitations of cell layout the full surface is not covered with cells. Increased packing density can be obtained, of course, but as the expense of additional complexity and cost. Assuming a fairly conservative cell stringing arrangement the minimum expected array output at the end of a 2 year life is 246 watts which is the same as the maximum beginning of life requirement.

5.3 Power Subsystem

The subsystem design is a conventional one based on that used for GIOTTO. The on-orbit power requirements are readily met by the solar array. The main problem is in the G.T.O. phase when eclipses and orientation of the spacecraft for p.b.m. firing lead to loss of solar input to the array. This case has to be covered by using batteries and the energy requirements turn out to be relatively large. From the power budget in G.T.O. it turns out that a continuous supply of 110 watts is required. Furthermore, calculation of the nominal time for which the spacecraft is turned away from the sun in G.T.O. leads to a value of 5 hrs. The batteries have therefore to supply 550 Whrs. Assuming 80% efficiency and 70% depth of discharge we require a battery capacity of 860 Whrs. This is similar to the GIOTTO requirement leading to four Ag-Cd batteries. However, mission analysis has shown that the DISCO spin axis can always be oriented so that some solar input to the array occurs. At certain times of the year this will require additional boost power and injection delta-v which can, in fact, be accomodated.

Since the solar aspect angle (S.A.A.) with respect to the array is a function of launch date and only exceeds 90° at two periods of the year a restriction on launch window could also be considered. The required battery power drops dramatically for even minor reductions in S.A.A. below 90° so that the battery power could be halved by reducing the launch window by 2 months covering the "power-peak" periods.

5.4 Attitude and Orbit Control Subsystem

The block diagram for this subsystem is shown in figure 5.2

5.4.1 Propulsion/Attitude Control

Propulsion is provided by a Mage 1s solid boost motor and attitude control by a hydrazine thruster system.

The boost motor is already qualified and presents no particular problems. The S.I. of 280s is capable of providing a boost delta-V of 1000 ms^{-1} to DISCO, which is adequate for reaching the L1 point.

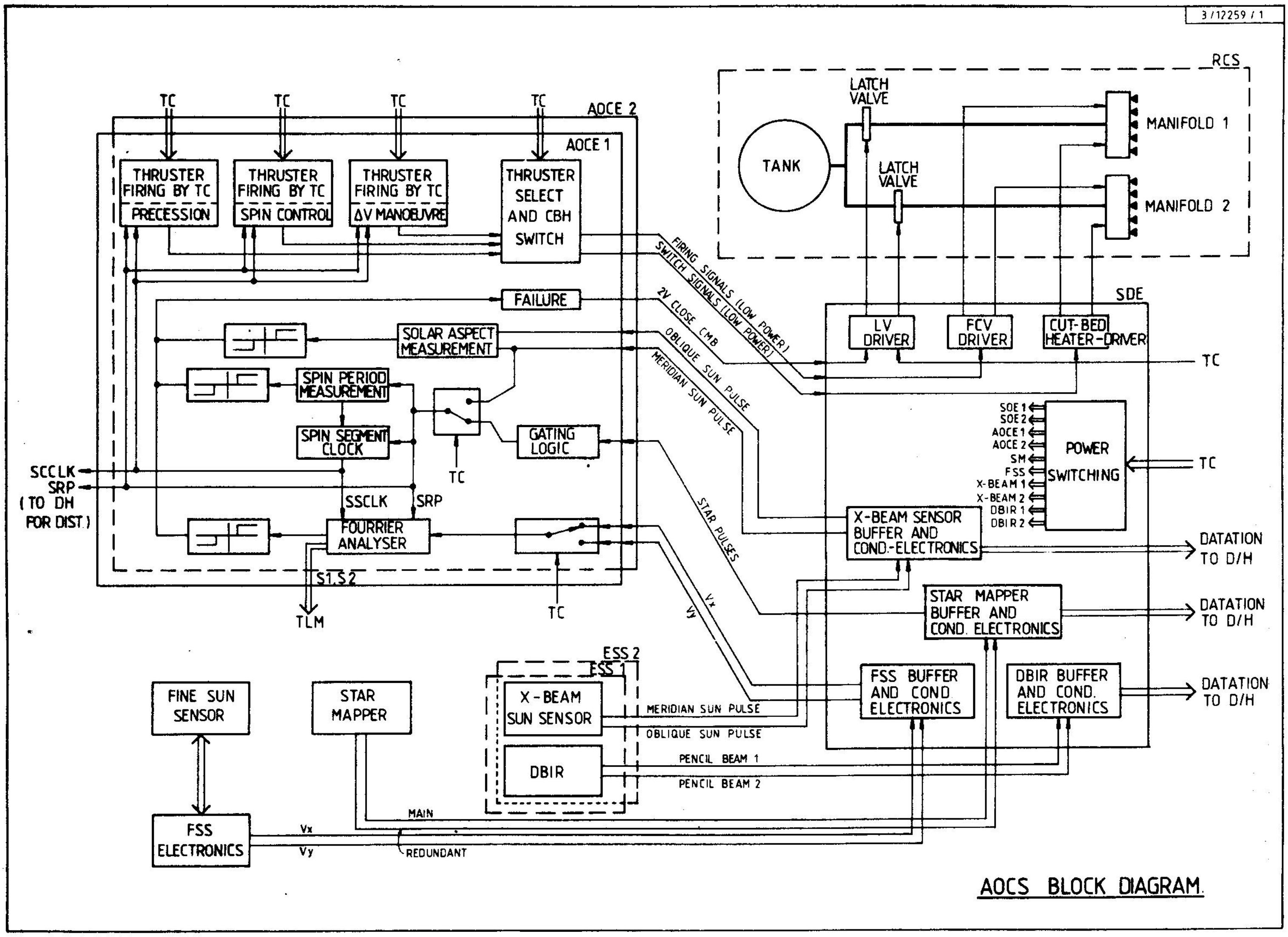


Fig. 5.2 AOCS Block Diagram

The baseline attitude control system is a central hydrazine tank carrying 132 litres of liquid hydrazine. The thrusters are mounted such that a pair of "spin" thrusters and one canted axial thruster are mounted on the short boom support brackets. A pair of redundant radial thrusters are mounted below the platform at one side of the spacecraft. This is in order to obtain a shorter moment arm for the daily manoeuvres which in turn reduces the magnitude of spacecraft-long boom dynamic coupling. Finally a pair of axial thrusters are mounted one each side of the spacecraft, also below the equipment platform but at the base of the spacecraft. 2N thrusters are used since these can deal both with on-orbit and mid-course manoeuvres.

A trade-off of the propulsion system was initially performed based on the factors of:

a) Performance (including contamination)
b) Cost (including qualification and testing)
c) Mass and Inertia
d) Reliability and complexity
e) Equipment availability within Europe.

Four main candidates emerged for the DISCO spacecraft viz.:

1) Unified bi-propellant system
2) Unified mono-propellant system
3) Bi-propellant + solid boost motor
4) Mono-propellant + solid boost motor.

Option 4) was selected for the following reasons:

- slosh/stability problem minimised because fuel can be stored in a central tank (with a diaphragm to control fuel movement)
- production and testing costs are relatively low
- solid motor performance allows fast injection into cruise orbit
- solid motor can be jettisoned, to relieve contamination problem, using straightforward known technology
- dry mass is relatively low
- European equipment is available.

5.4.2 Attitude Measurement

This subsystem has to achieve a number of performance levels arising from:

a) payload operating modes and requirements
b) spacecraft mission requirements.

These requirements are summarised in tables 5.1 and 5.2. In order to achieve these requirements, a set of on-board sensors has been baselined for the spacecraft and these are listed in table 5.3, together with comments regarding their application.

The most severe requirements for the sensors are:

a) spin reconstitution of s/c to an accuracy of 2 arc mins.)onboard
b) sun sensor accuracy of 1 arc min)
c) sun sensor signal ground processing.

Regarding a) a trade-off has been performed between star mapper and earth sensor. An earth sensor would be a lower cost item but could not achieve the 2 arc mins requirement. The best performance would be around 5 arc mins degrading to 1˘ during the manoeuvre phase, due to spacecraft nutation.

Table 5.1 Requirements arising from payload

Function	Requirements
. Spin rate	5 r.p.m.
. Principal spin axis alignment	along s/c - sun line, nominally pointing to within ± 30 arcmin of sun centre throughout the operational life.
. Principal spin axis absolute pointing accuracy (during imaging for 4 hrs max.)	± 4 arcmin. with goal of ± 1 arcmin. (95%).
. Spin axis relative pointing accuracy	10 arcsec. over any 1 minute period during 4 hrs imaging time.
. Spin axis attitude measurement accuracy	1 arcmin. on-board with goal of 5-10 arcsecs reconstitution by on-ground processing.
. Spin period measurement accuracy	0,1% (95%)
. Spin phase angle measurement accuracy	2 arcmin. (95%)
. Variation of s/c velocity along l.o.s.	20 m/s/day
. Short term s/c l.o.s. velocity stability	1 mm/s
. Lifetime	2 years

Table 5.2 Requirements arising from mission operatings

Event	AOCMS Requirement	Comments
. Launch and separation	-	A.O.C.S off s/c prolate
. G.T.O. (several orbits)	- maintain s/c sun pointing - maintain spin rate	
. Slew for TPS burn	- open loop pulsed manoeuvres	slew to x = 90°
. Spin up to TBD r.p.m.	- open loop spin change - attitude sensors must operate at high spin rate	-
. T.P.S. burn	-	solid T.P.S.
. Despin, re-orient to sun pointing	- open loop spin change - open loop pulsed manoeuvre	-
. TPS ejection	-	-
. First Delta-V	- open loop pulsed manoeuvre - continuous firing (axial thrusters)	"turn and burn" strategy assumed
. 2nd and 3rd Delta-V	- continuous firing (axial thrusters - pulsed firing (tangential thrusters)	-
. cruise orbit	- maintain s/c sun pointing - maintain spin rate	
. L1 injection	- continuous firing (axial thrusters - pulsed firing (tangential thrusters)	
. Operational orbit	- see table 4.4.1	

Table 5.3 Summary of baseline sensor set

Item	Quantity	Function
. Fine Sun Sensor	1 (sensor has two slits giving inherent redundancy	- primary attitude sensor - used throughout cruise and operational orbits (except 1st mid-course during G.T.O.)
. X-beam Sun sensor and dual beam I.R. sensor	2 (redundancy)	- sun sensor used to provide spin phase/rate and solar angle measurements during G.T.O. and 1st mid-course - DBIR sensor used to provide second axis attitude information during G.T.O.
. Star mapper	1 (Internal redundancy assumed)	- provides spin phase/period measurements - used throughout cruise and operational orbits (except 1st mid-course) and possibly during G.T.O.

The TPD star mapper used on GIOTTO has been baselined but study has revealed that suitable reference stars are not available throughout the year. The use of Canopus as reference was considered but since this is 17° away from the ecliptic pole it is not in the field of view of the star tracker all year. It is therefore suggested to modify the star tracker f.o.v. to 40° in order to use Canopus as the reference star.

The most suitable sun sensor to meet the attitude measurement accuracy required seems to be the Adcole 20910, used on L-Sat. This has a 32° f.o.v. and will require modification to be used on a spinning spacecraft. It is a crossed slit sensor and the sinusoidal signals from each slit are processed by a "CONSCAN" processing method which effectively eliminates bias errors. This is shown schematically in Fig. 5.3.

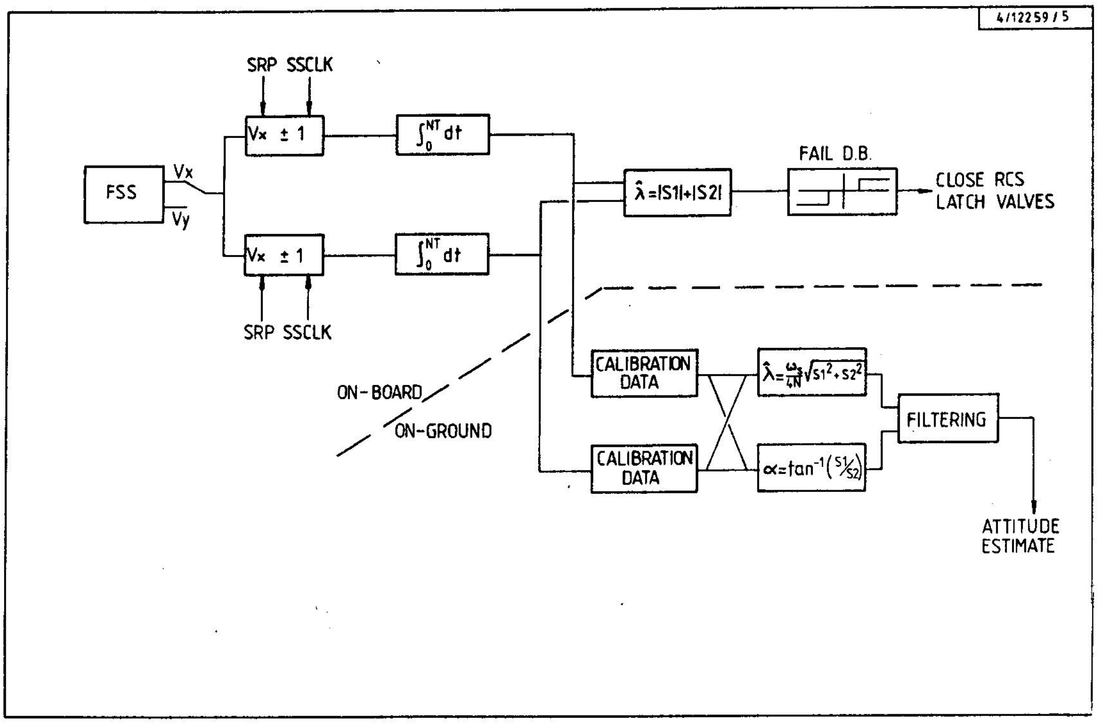


Fig. 5.3 Attitude Measurement System

It is not known whether the goal of 5-10 arc secs reconstitution accuracy after ground processing can be achieved. However, by comparing the nominal measured with the actual solar drift rate and direction and taking sufficient averaging to minimise random effects a processed value of below 30 arc secs. should certainly be achievable.

5.5 Telemetry

This consists of two separate systems viz. the low gain and the high gain antenna systems.

The low gain system consists of two patch antennae on the forward face (central cylinder) of the spacecraft and a conical antenna on an

extension rod at the rear. This gives an omni-directional beam coverage with minimum gain of -4dBi. This system is used in G.T.O. The rear extending conical antenna is ejected with the boost motor. However a further pair of patch antennae on the rear of the spacecraft is uncovered for use in the cruise phase.
For insertion manoeuvres (into L1) the distance is too great for the L.G.A. to be used. There are then three alternatives possible:

1. Put a deep space transponder on board. This is rejected because of the high cost.
2. Use the high gain antenna. This will give a high fuel penalty (20% greater than nominal insertion requirements).
3. Use the Weilheim 30 metre antenna.

The practical solutions are either 2 or 3 and which one to use can be decided operationally later in the programme.

The high gain antenna to be used is a Corrugated Horn. This gives adequate gain right to the extremes of the Halo orbit (27° as seen from the earth).

A conical horn with septum polarizer was initially considered but the chosen item gives improved circular polarization at wide beamwidth. It will be 19 cm in diameter and 10 cm long. the polarizer consists of two probes, inserted at right angles into the waveguide, originating from a phase delay circuit. The section of waveguide required to generate the circularly polarized output will be about 10 cm long. The maximum antenna gain will be 10 dB falling to a value of 7 dB at ± 25° away from the beam centre.

The use of a shaped beam antenna has been investigated but the cost and complexity of this development is not felt to be justified for DISCO. It is recommended that a convolutional coding/Viterbi decoding scheme is introduced (as for ISPM, GIOTTO and HIPPARCOS missions) in order to bring gain performance closer to the nominal requirement at the high angular offsets.

5.6 On-Board Data Handling

The O.B.D.H. subsystem is based on that of ISPM. A memory unit is included which contains two (redundant) tape recorders (giving a 40 Mbit storage capacity) plus back-up 6 Mbit semiconductor store to ensure continuous coverage for the relevant solar pointing instruments. A back-up solution would be a bubble memory store instead of the tape recorders, since this would be a wholly European solution. The decision would depend to some extend on the state of development of these devices by SAGEM at the time of DISCO "go-ahead".

Switchable bit rates of 2 Kbits, 3Kbits and 4 Kbits are included in order to cater for the varying halo orbit coverage.

The instrument bit rate requirements are listed in the following table:

Instrument	Data Rates (b/s)		Comments
	In Contact	In Contact	
Solar pointing			
HRS	15	15	Uninterrupted data stream for one year minimum
AR4	3		
SP6	14	10	
APH	5	5	
Sub-total	37	30	
FUV	-	100	Max. of 4 hours/day
Heliospheric			
MAG	80	80	
RWR	30	30	
PWA	80	80	
SWI	400	100	
SWE	100	25-80	
LEP	80	80	
HEP	100	100	
XGR	40	40	
Sub-total	910	560	
TOTAL	947	690	for 4 hrs maximum
	=====	590	for remainder
		======	

Nominally it is assumed that the ground station in-contact period is 8 hours and out-of-contact 16 hours (but see section 2.4), leading to a maximum requirement of around 2,5 Kb/s real time transmission and a 40 Mbit on-board store assuming 100% coverage for the heliospheric instruments. However, further modulation of the nominal link margin occurs as a function of the Halo orbit amplitude, the variation being about ± 1,2 dB over a 6 month period. To cope with this variation it is recommended to baseline a nominal real time data rate of 3 Kb/s with switchable rates corresponding to (say) 2 Kb/s and 4 Kb/s. It should be noted that even in the "degraded" mode of 2 Kb/s then 80% of the low-rate solar wind data can be transmitted.

Although a single ground station (Villafranca) is baselined for DISCO for cost reasons, the use of two stations simultaneously (Villafranca and Carnarvon) has been investigated. DISCO coverage from Carnarvon depends on the phase of the Halo orbit with respect to the seasonal declination of the sun. However, it seems that using this second station could reduce the on-board data storage requirements by approx. 50%. Regarding Carnarvon itself it is assumed that the majority of the T.T. & C. systems procured for GIOTTO will be compatible with DISCO. However a digital recording system with associated software would have to be developed and a data line from ESOC (Darmstadt) to Carnarvon installed.

6. SYSTEM BUDGETS

The major spacecraft budgets are summarised in this section in tables 6.1 to 6.4.

6.1 Mass Budgets

Subsystem	Mass kg
Structure	78.0
Thermal	14.4
AOCMS	18.0
RCS	39.3
Data handling	27.1
TT & C	22.3
Power	37.9
Harness	34.0
Solar Cells	3.6
Experiments	94.5
TPS	35.6
Total Dry Mass	404.7
Contingency	73.4
Balance & Ballast	26.3
Hydrazine	132.0
TPS Propellant	268.0
Launch Mass	904.4

6.2 Power Subsystem Budgets

Subsystem	Power (watts)			
	G.T.O.		On Station	
	Constant	Peak	Constant	Peak
Payload	-	-	125.5 with FUV 95.5 without	
Data Handling	11.5	11.5	11.5	11.5
A.O.C.M.S Converter	10.5	13.1	10.5	13.1
Data Handling	-	-	7.4	7.4
Tape Recorder	-	-	9 (record) 5 (standby) 14 (playback)	
T.T. & C.	40.0	40.0	9 (no contact) 40 (in contact)	20 extra 0.4s RFDU switching
Decoders	10.0	10.0	3.2 (standby)	10 (active)
Power s/s losses	14.5	14.5	14.5	14.5
Heaters	-	18.8	0	0
Platform Heaters	T.B.D.	T.B.D.	0	0
Catalysted Bed Heaters	-	11.2	-	11.2
Thrusters	-	4.6 each	-	4.6 each
TOTALS	99.5	136.3	187.7 FUV off 222.2 FUV on	233.7 RCE off 245.8 RCE on.

6.3 Link Budgets (Margins)

Telemetry Margins

Mission Phase	Bit Rates b/s	Carrier	Margin dB	Telemetry	Margin dB	
		NOM	ADV	NOM	ADV	
Near Earth	100	16.8	14.6	20.3	18.0	
Cruise	100	10.1	7.9	13.6	11.3	
Injection (Weilheim)	100	2.4	0.2	5.8	3.5	
Halo orbit	2000	3.4	0.5	3.6	1.4	
	3000	3.4	0.5	1.8	-0.4	1
	4000	3.4	0.5	0.5	-1.-	2

1. 3kb/s available for 75% of the time under adverse conditions
2. 4kb/s available for 40% of the time under adverse conditions

Adverse figures are 1dB + RSS below nominal

Telecommand Margins

Mission Phase	Rx Input dB	Margin	Carrier dB	Margin	Telecommand dB	Margin
	NOM	ADV	NOM	ADV	NOM	ADV
Near Earth	6.9	5.4	20.6	18.9	23.1	21.5
Cruise	5.0	3.5	22.7	21.0	25.2	23.6
Injection (Weilheim)	10.2	8.7	21.9	20.3	24.4	22.8
Halo orbit	5.0	3.5	22.7	21.0	25.2	23.6

Adverse figures are 1 dB plus RSS below nominal
Telecommand bit rate 125b/s

Ranging

Mission Phase	Ranging Tones S/N dBHz	
	NOM	ADV
Nearth Earth	33.7	31.0
Cruise	21.4	17.9
Injection (Weilheim)	20.0	17.4
Halo orbit	21.4	17.9

Adverse figures are 1dB + RSS below nominal
Minimum acceptable S/N : - 10dbHz

6.4 Fuel Budget (Hydrazine)

Operational manoeuvre	Delta-V	Fuel mass (kg)
Slew for TPS firing	(35° at 10 r.p.m)	0.12
Spin up to 90 r.p.m.	-	1.58
Despin to 5 r.p.m.	-	1.58
Initial sun acquisition	(90° at 10 r.p.m.)	0.29
Spin trim for rigid boom deployment	(0.89 r.p.m.)	0.02
Attitude manoeuvre	(2 x 180°)	0.39
1st mid-course Delta-V	60 m/s (//to spin axis)	18.14
2nd mid-course Delta-V	75 m/s (at 45°)	1.58
3rd mid-course Delta-V	1.0 m/s (at 45°)	0.21
Sun motion in cruise orbit	(150°)	0.68
Attitude manoeuvre for L1 insertion	(2 x 180°)	0.79
L1 insertion Delta-V	165 m/s (//to spin axis) (worst case)	51.53
Spin trim for wire deployment	(1.5 r.p.m.)	0.04
Station keeping	10 m/s (for 2 yrs)	7.31
Sun motion	(360°/yr for 2 yrs)	8.03
Spin trim	(25 r.p.m.)	0.79
TOTAL		94.9
Notes		
1. Assumed dry mass		457.7kg
2. Satellite spin rate		5 r.p.m.
3. Thruster lever arm		1.0 m
4. Thruster angle		30°

7. SPECIAL ASPECTS

The following aspects are presently seen as requiring special emphasis during the early phase of satellite development:

1. Spacecraft Dynamics - continuing analysis of the long boom dynamic coupling with the spacecraft in order to devise a strategy for meeting the pointing requirements compatible with spacecraft manoeuvres. This also has strong influence on attitude measurement and propulsion subsystems.

2. Mission analysis - optimisation of cruise and insertion to remain compatible with fuel supply and year round launch. Optimisation of Halo orbit parameters with further analysis of tracking performance and errors.

3. Spacecraft line of sight velocity stability and measurement - derive strategy for keeping spacecraft delta-V below 1 mm/s for daily manoeuvres. For orbit manoeuvres it seems likely that 1 mm/s is exceeded but knowledge of delta-V to this accuracy is still necessary. Implications of using on-board accelerometers require further examination.

4. Solar array - impact of annular shape on cell layout.

5. Power subsystem - use of batteries in G.T.O.

6. Attitude measurement - development of large f.o.v. star mapper. Modification of f.s.s. to use on spinning spacecraft. Reconstitution of f.s.s. data to give high attitude measurement accuracy.

7. Telemetry - development of high gain antenna.

8. O.B.D.H. - high capacity store with back-up store for solar experiments.

8. MANAGEMENT AND SCHEDULE

8.1 Science Management

After approval of the mission, the Agency will issue an Announcement of Opportunity (AO) calling for proposals for the instrument development. The AO will be explicit in terms of the spacecraft mission and resources, technical interfaces, schedule, deliverable items, responsibilities of the parties, observer programme, etc.

Scientific collaborations or principal investigators are expected to respond with proposals describing in detail the design and development of the envisaged instrument in addition to the scientific objectives.

The proposals should describe the management structure within the collaboration and show how responsibilities for the scientific, technical, operational and analysis aspects will be discharged.

Each instrument will be funded nationally and will be developed under the responsibility of a Principal Investigator who will constitute the point of contact for the ESA project team. A project scientist appointed by ESA will coordinate the work of the Principal Investigators with regards to overall optimisation of the mission.

Selection of the payload will be via the normal procedure of technical evalutation by the Executive recommendations by the ESA advisory groups and approval by the SPC.

8.2 Technical Management

It is proposed that procurement of the spacecraft be managed in the usual manner, with Phase B study and Phases C/D industrial procurement contracts funded and placed by ESA. The scientific instruments would then be nationally funded and delivered to ESA by specified dates. Responsibility for monitoring the industrial contract and provision of liaison between the contractor and instrument procurements groups would lie with the ESA project team.

The contractor for Phases B-C-D will be responsible for the following activities:

- to assist ESA in mission analysis and system specification
- to develop and qualify the spacecraft system and subsytem
- to assist ESA in specification of experiment interfaces and acceptance of experiment hardware.

8.3 Model and Test Philosophy

The baseline chosen for DISCO is a two model programme using one development plus one flight model.

The development model will be used sequentially as a structural and electrical model and major tests will be:

- dynamic testing to verify structural analysis and design
- verification of structural and electrical interfaces.

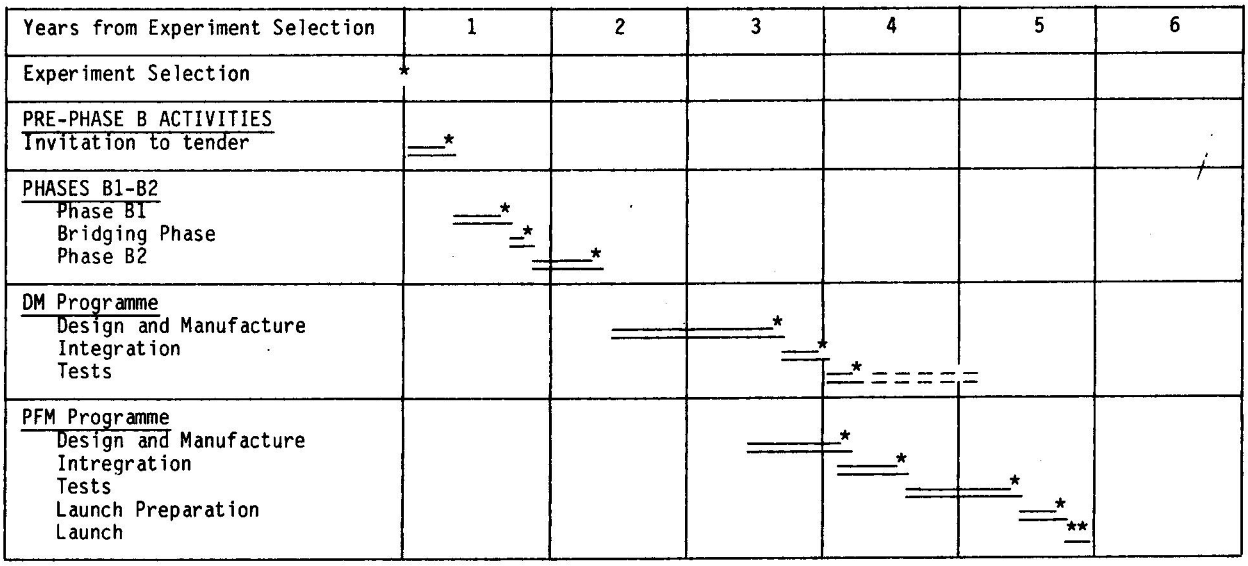
No thermal model is proposed since it is considered that in view of the stable thermal environment sufficient confidence can be placed on analysis techniques. However, a worthwhile option would be to consider (during phase B) the implications of restricted thermal tests on the development model (which would not be fully thermally representative).

The Protoflight Model (PM), assembled with full flight standard units and sub-systems will be used to demonstrate system level qualification. The full range of testing will be performed including alignment, EMC and antenna pattern, solar simulation, acoustic, vibrations, thermal vacuum, RCE leak checks, electrical and mechanical performance and mass properties.

8.4 Development Programme

The programme stages up to launch are shown in Fig. 8.1. As can be seen DISCO can reasonably be expected to be on-station at a time which is fully compatible with the ISPM mission, the solar polar passes for the latter spacecraft presently being scheduled to take place around early and late 1990.

Figure 8.1 DISCO DEVELOPMENT SCHEDULE



Notes: DM Development Model
PFM Protoflight Model

APPENDIX A

Payload: Instruments description

The descriptions are more extensive in those instruments that are relatively new for spacecraft operation.

1. HIGH-RESOLUTION SPECTROPHOTOMETER (HRS)

There are numerous possibilities for designing a High Resolution Spectrophotometer tailored to solar velocity observations, some of which have already been used on the ground. In the model payload we have selected one of the proven solutions which seems to constrain the weight and power allocation most, namely an alcaline resonance cell operated with sodium rather than potassium vapour, since the working temperature and magnetic field intensities are higher in the sodium case.

The principle of the instrument can be summarised as follows:

The Doppler shift of the sodium D1 Fraunhofer line is deduced from differential monochromatic intensity measurement in both wings of the line.

Absorption of linearly polarised solar light, by a sodium vapour in a small optical cell, placed in a magnetic field of about 5000 gauss (provided by a permanent magnet as well shielded as possible), allows the separation of two spectral windows corresponding to the σ^+ and σ^- Zeeman components. Observation of the scattered light in the direction of the magnetic field through an electro-optic modulator allows a photomultiplier to measure alternatively intensities I_r and I_v proportional to monochromatic intensities in the red and violet wing of the solar line. The bandwidth of these spectral windows ($\sim$ 0.050 Å) is determined by the temperature of the sodium vapour (165^o C), the hyperfine Zeeman structure and the inhomogeneity of the magnetic field.

The high photometric and spectral stabilities required by the needed sensitivity is provided by an accurate control of the temperatures of the sodium cell and of the prefilter, as well as by the stability of the permanent magnet. Operating in integrated sunlight with a telescope diameter of about 6 cm, this apparatus gives, at the photomultiplier output, a mean current of 10^8 electrons/s. The statistical noise is then 10^{-4}, which corresponds to 1 ms^{-1}, with a time constant of 1 second, and it can therefore be reduced below 10^{-3} ms^{-1} by integrating over two weeks or more.

All electronic circuitries and thermal control, as well as the rate of A-D conversions and data acquisition are designed to ensure that instrumental noise will always be significantly below statistical photon noise.

The entrance mirror of the HRS experiment is actuated in order to keep the rest of the optics aligned with the sun centre within 10". This fine pointing mirror is anticipated to be able to track properly the sun provided it is within 1^o of the experiment axis.

2. TOTAL SOLAR IRRADIANCE

Two radiometers of independent design and manufacture are proposed to measure the short and medium term variations (hours to years) and to contribute to the observation of its possible long-term variations (solar cycle). The absolute character of these instruments makes it impossible to calibrate them and although both instruments have means to control their performance, only the comparison of two different experiments may give enough confidence to check unforeseen ways of ageing or degradation. An absolute accuracy of better than 0.2% can be guaranteed over the time of the mission. The relative precision is of the order of 10^{-6}. For the measurements of luminosity oscillations a high precision radiometer with a resolution of 1 ppm is added.

2.1 The Absolute Pyrheliometer (APH) consists essentially of two separate heat sensors each mounted under a shutter. The heat sensors are cylindrical active cavities where the solar radiation energy is compared with electrical energy. One of the cavities is used to determine the ageing of the other.

2.2 The other package (AR4) has 4 channels: a thermopile instrument with high resolution for continuous measurements, 1 Active Mode Radiometer continuously operated, and 2 active mode radiometers, spare for degradation detection. The active mode radiometer uses an electrically heated cavity with an inverted cone as absorber for the radiation. One of the candidates for degradation is the cavity absorptance. Hence, a reflectometer is built in one of the active mode radiometers in order to measure the reflectance in orbit and to enable corrections for possible degradation.

3. SOLAR SPECTRAL IRRADIANCE

6 channels of sunphotometers (SP6) measuring the solar spectral irradiance at fixed wavelengths with moderate resolution in a range from 250 to 1000 nm are used for the long-term continuous monitoring of the solar luminosity variability and oscillations and its spectral dependence.

The basic design is very simple: a silicon photodiode is used as detector and views the sun through an interference filter (3-4 period dielectric filter) and a view limiting tube. Three such detector-filter combinations are comprised in one sensor head, which is temperature-stabilised at about 40°C with an electrical heater. As this heater is on during the whole degassing phase of the satellite, the filter and detector surfaces will be kept clean. The three sunphotometers in one head are basically identical. One is used continuously and the two spare ones are exposed to the sun only about once a month and are used to detect eventual degradation of the continuously exposed one.

In order to enable accurate accounting for the continuously varying angle between the line of sight to the sun and the instrument axis an accurate pointing measurement system is incorporated. The reconstitution of the angle is done for each spin period to an accuracy of better than 3 arc sec allowing correction down to 0.1 ppm of the signal.

4. FAR-UV SPECTROHELIOGRAPH (FUV)

The far UV spectroheliograph will be able to build up pictures of the far UV corona with a resolution of 15 to 30 arc sec in the range extending from 150 Å to 1350 Å, while at the same time providing good spectral resolution to separate lines for diagnostic purposes. The spacecraft rotation allows the field of view to be analysed along a series of circles concentric with the intersection of the spin axis and the focal plane.

Time resolution need not be high (a few hours). However, the speed of data acquisition must be fast enough to eliminate any blurr due to the satellite rotation.

The model instrument consists of a grazing incidence telescope to isolate small picture elements on the solar disc followed by a grazing incidence spectrometer for spectral studies.

The telescope has a focal length of about 30 cm. It is a sector of a Wolter Type I telescope. The grazing incidence angles are small enough to ensure good transmittance down to wavelengths $\lambda \sim 150$ Å. Within the useful field of view a complete image of the solar disc is obtained at an adequate angular resolution (∿ 15 arc sec) by means of a pinhole which scans a solar radius from sun centre to a distance of 25 arc minutes under the action of an internal mechanism. This pinhole also serves as the entrance slit for the spectrometer and its motion parallel to the grooves of the grating has no effect upon the bandpass.

An auxiliary mechanism can adjust the position of the pinhole in the focal plane to correct for any misalignment problems and permits the avoidance of an appearance of a blind zone in the solar pictures. The dispersive element in the spectrometer is a grazing incidence concave grating used in a Rowland circle mount. The detector is a two-dimensional channeltron array. The count rates from all pixels illuminated by each of the selected solar spectral lines in the range 150 - 1350 Å are summed in order to determine the corresponding spectral flux admitted within the single picture element of constant size and varying position.

A low dispersion channel will serve as an onboard standard in order to provide long-term validation of the photometric properties of the imaging spectrometer. This will be achieved by a design minimising the number of optical components (1 grating - 1 detector) and scheduling a very parsimonious use of this device (in order to reduce ageing):The total operational cycle will be less than 1 hour per day, each grating being exposed to the sun for about 15 minutes.

The integrated flux from the complete solar disc will be obtained from one single measurement at each wavelength. Thus it will be possible to renormalise each solar image on an absolute scale. This will be crucial when emissions at widely separated wavelengths must be compared.

5. MAGNETOMETER (MAG)

The instrument in the model payload is a fluxgate magnetometer. The performance of magnetometers currently used in space is more than adequate to measure the interplanetary magnetic field.

The magnetic field is to be measured with a bandwidth of DC to about 4 Hz. The long term absolute accuracy of current instruments is better than 0.1 nT, the RMS noise integrated in the frequency band is less than 0.01 nT. Drifts with time and termperature are no more than a few times 0.01 nT. The critical parameter in the definition of the system is the magnetic environment of the sensor, due to the stray fields of the spacecraft, not more than 0.3 nT in magnitude and not varying more than a few times 0.01 nT.

6. ELECTROMAGNETIC WAVE EXPERIMENT

6.1 Radiowave Receiver (RWR)

Using two antennas, one in the spacecraft spin plane and the other along its spin axis, it is possible to obtain the direction of the line-of-sight of a radio source. This will be done from the ISPM spacecraft. To localise the source on the line-of-sight it is necessary only to determine, from some distant spacecraft, the plane containing the radio source; the intersection of the plane and the line uniquely localises the source. Only a spin plane antenna is therefore required to determine the source plane; this is done by the DISCO experiment, with a 72 m tip-to-tip antenna.

6.2 Plasma Wave Analyser (PWA)

The experiment comprises three sensors: the radio astronomy wire antenna which measures the electric field E_x, and AC magnetic sensors which measure the two magnetic field components B_y and B_z, the latter being parallel to the spacecraft spin axis. Spectral information is obtained in two ways: by a swept-frequency receiver for the higher frequencies (0.5 - 35 kHz), and by on-board microprocessor analysis of the field waveform at the lower frequencies (0.2 - 500 Hz).

7. PLASMA ANALYSERS

The plasma analysers produce, with the help of on-board processing, basic parameters that describe the distribution of protons (moments of the distribution function), α-particles and electrons with high time resolution.

7.1 Solar Wind Ion Analyser (SWI)

It comprises an electrostatic analyser to determine the mass and velocity distribution in 3 dimensions of the solar wind ions. The energy range between ∿ 200 eV and ∿ 20 keV/charge covers well the distributions around typical solar wind velocities, i.e. between about 200 and 800 km/s.

The instrument needs to cover only up to 22° away from the Sun direction to obtain a 3-dimensional velocity distribution of the ions.

7.2 Solar Wind Electron Analyser (SWE)

An electrostatic analyser is used to measure the energy and angular distributions of solar wind electrons. The energy range of 1 eV to 1.5 keV is covered. To obtain a 3-dimensional distribution, the instrument's field of view is fan-shaped: 130° (in plane containing the spin axis) full width, centred at 60° from the solar direction.

8. ENERGETIC PARTICLES

8.1 Low Energy Particle Directional Spectrum Analyser (LEP)

It consists of 4 particle telescopes pointed at 30°, 70°, 110° and 150° with respect to the spacecraft spin axis. Each telescope contains a stack of solid state detectors to measure the energy spectrum of low energy protons, α-particles and perhaps some heavier nuclei up to about 10 MeV/nucleon. Directional distributions are measured using the different viewing directions of the telescopes, and the spin of the spacecraft.

8.2 Medium to High Energy Particle Telescope System (HEP)

A dual particle telescope system is foreseen, mounted within the same box, with viewing cones centred at 90° from the spacecraft spin axis. One particle telescope is designed for the higher energies, say 40 MeV/nucleon to 200 MeV/nucleon, and will also measure electrons of energy greater than 3 MeV. The other telescope is optimised for measuring the composition of the "anomalous component" of cosmic rays, i.e. He, C, N and O nuclei between 1 and 40 MeV/nucleon. This second particle telescope will also measure the composition and intensity of high energy solar particles associated with solar flares.

9. SOLAR FLARE X-RAY AND COSMIC GAMMA-RAY BURST DETECTORS

The detector package on DISCO should match the ISPM instrument for direct correlation and triangulation of events. The boom-mounted sensor consists of two parts. One part contains two passively cooled silicon surface barrier detectors to measure solar X-rays in the 5 - 15 keV energy range. The second part consists of hard X-ray (15 - 150 keV) detectors; it comprises two photomultiplier/scintillator assemblies, having a nearly unobstructed 4π field of view.

APPENDIX B

RELATED MISSIONS AND PROJECTS

Helioseismology

- A heliocentric solar observing station following the Earth on its orbit at a distance of 90° has been considered in the Soviet programme, but this mission has neither been defined yet nor has it been approved.

- NASA had described in very broad terms a mission to study the interior of the Sun, the Solar Internal Dynamics Mission, whose objectives are indeed in the spirit of DISCO with probably more emphasis on the study of the solar dynamics. After a meeting organised by NASA in early 1982 at Boulder, at which most of the active US scientists in the field were present, it was decided that a special study group would be convened to define more precisely the aims of this mission. To our knowledge, to date, this study group has not yet been formed.

- A network of multiple ground-based stations (9) allowing continuous solar observations is presently being envisaged in the UK. The use of several spectrometers operating at different sites and different wavelengths offer the great advantage of firmly establishing the solar origin of any signal observed. Therefore, it is considered of the utmost importance that simultaneity of observations with DISCO and from this network be ensured during the time of the mission.

Heliospheric physics

- The International Solar Polar Mission (ISPM) to be launched in May 1986 will be at high solar latitudes in 1989/1990.

- NASA made a definition study of SIS (Solar Interplanetary Satellite), carrying the payload of the cancelled NASA ISPM spacecraft and being in a drift orbit at 1 AU some 90° behind the Earth. It was under consideration for a new start in NASA's FY 1984. Its status will be known in late January 1983. If approved it would constitute with ISPM and DISCO an excellent complement of spacecraft to study 3-dimensional aspects of the Sun and the Heliosphere.

- NASA conducts definition studies of the OPEN (Origin of Plasmas in the Earth Neighbourhood) project, comprising 3 magnetospheric and 1 interplanetary spacecraft. The Interplanetary Laboratory (IPL) carries only field and particle instrument and is planned for a L_1 orbit. The earliest new start of OPEN is in NASA's FY 1986 with an earliest launch of IPL in 1989.

- ISEE-3 observations will cease in 1986. It was moved from its halo orbit around L_1 in the autumn of 1982, to study the deep geomagnetic tail in 1983 and to fly across the wake of comet Giacobini-Zinner in September 1985. Even under the most favourable circumstances, ISEE-3 will be at the limit at which its radio signals can be detected by late 1986.

- Some Pioneer 10/11 and/or Voyager 1/2 data from the outer heliosphere ($R > 20$ AU) may be available beyond 1988.